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X-RAY INVESTIGATION IN AVIATION AND SPACE MEDICINE

A. R. Mansurov

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16. Abstract

The history of the use of x-rays to study the effects produced in animals and man by g-forces oriented in various directions is presented with reference to Soviet and foreign literature. Frequent comparisons are drawn between the effects on unprotected organisms and parts of the body and the same effects ameliorated by the use of pressurized clothing and special g-suits. Data drawn from examinations of professional aviators and parachute jumpers are employed in a survey placing special emphasis on spinal changes and damage caused by landing after ejection or making a jump.

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DEDICATION

This modest work of mine is dedicated to the shining memory of the first cosmonaut in the world, Yuriy Alekseyevich Gagarin.

FOREWORD

It is well known that flight aboard supersonic aircraft and spacecraft requires the solution of many medical and biological problems in addition to overcoming considerable technical difficulties. This monograph by Doctor of Medical Sciences. Professor A. R. Mansurov, is devoted to one of the timely problems of aviation and space medicine — the study of the influence of abrupt and prolonged g-forces, angular accelerations, and explosive decompression on the organism. The author, calling upon a broad range of x-ray methods of investigation and possessing a deep and far-ranging understanding of the field of applied physiology and pathomorphology, has performed some extremely interesting and practically important investigations. These studies were performed on remarkable devices using modern x-ray methods. Some of the data obtained by the author are the first in the Soviet Union.

The book presents original data which are of enormous theoretical and practical significance for the further development of aviation and space medicine. The author clearly shows that the x-ray method of investigation makes it possible to gain a much fuller understanding and trace the dynamics of the functional and morphological changes that occur in various organs and systems when the organism is subjected to g-forces and changes in barometric pressure. He has not limited himself to a systematization and description of x-ray material alone, but has compared these data with the results of clinical, physiological and whereever possible pathomorphological research.

The basic views of this work are reflected in papers delivered at the 8th and 10th Congresses of the All-Union Physiological Society, at the 2nd International Symposium on Space Medicine in Paris, two conferences on aerospace medicine, and in papers published in various books and journals.

The monograph by Professor A. R. Mansurov is an important contribution to Soviet roentgenology in the field of aviation and space medicine. A number of new ideas contained in the work will be used successfully by other specialists.

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X-RAY INVESTIGATION IN AVIATION AND SPACE MEDICINE

A. R. Mansurov[1]

INTRODUCTION

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The space era began with the launching of the first artificial Earth satellite in the Soviet Union on the 4th of October 1957. This day is now marked all over the world as the International Day of Man's Entry into the Space Age.

On the 12th of April 1961, the "Vostok" spacecraft carrying pilot-cosmonaut of the USSR Yu. A. Gagarin was launched into orbit as a satellite of the Earth. After making one revolution around the Earth, he landed safely in the specified area. For the first time, man had been exposed to completely new physical, biological and emotional spaceflight conditions and had withstood this difficult trial. It is remarkable and highly symbolic that the principal achievements of space technology and the first manned spaceflights were performed in the Soviet Union.

The success of the first manned spaceflight was preceded by numerous medical and biological studies conducted in the Soviet Union by a large collective of scientific specialists in the field of aviation and space medicine, headed by distinguished Soviet scientists — V. V. Strel'tsov, V. V. Parin, O. G. Gazenko, D. Ye. Rozenblyum, G. L. Komendantov, A. G. Kuznetsov, P. K. Isakov, D. I. /8
Ivanov, A. M. Genin, M. P. Brestkin, V. I. Yazdovskiy, and others.

Highly complicated experiments were performed under terrestrial conditions, imitating spaceflight conditions and studying the influence of various extremal factors on the organism: high degrees of rarefaction of the atmosphere and breathing under increased pressure, g-forces, prolonged isolation and hypodynamia, vibration, etc. In order to clarify the physiological mechanisms of the abnormalities which arose in the organism as a result of these influences, a wide range of methodological procedures was employed, with the x-ray method of investigation being of no little importance.

This method had been used earlier in the field of aviation and space medicine. However there were still only a few studies that were devoted to the x-ray study of various processes occurring in the organism under conditions of exposure of the latter to extremal flight conditions. This was due mainly to the considerable methodological difficulties associated with the use of complex x-ray apparatus under these conditions.

The development of aviation and cosmonautics was accompanied by a rise in the development of aviation and space medicine, whose most important task was

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[1]Doctor of Medical Sciences.

*Numbers in the margin indicate pagination in the foreign text.

the study of the influence of extremal factors on the organism (brief and prolonged g-forces, angular accelerations, explosive decompression, etc.), occurring during flights aboard modern aircraft. While some of these factors (prolonged exposure to g-forces) occur on all flights, others (angular acceleration, abrupt exposures to g-forces of high magnitude and explosive decompression) occur as a rule only in emergency situations.

In solving the complex problems associated with ensuring safety in high /9
altitude and spaceflights, an important role was played by the introduction of pressurized cabins for the crew, making it possible to create and maintain in them an artificial microclimate at all altitudes. However, the danger of failure of the cabin pressurization could not be excluded, and this would result in a change in the barometric pressure or a rapid drop in the latter. If this drop is sufficiently great and occurs in a very short space of time, serious traumatic injury to the internal organs may result.

As a rule, a high degree of tolerance to g-forces and explosive decompression on the part of the organism can be ensured by taking a number of preventive measures. In order to solve this problem, it is necessary to be familiar with the mechanism of development of pathological changes and the compensatory--accommodative reactions of the organism which arise as a result of exposure to the action of unfavorable factors.

Principal attention in this work has been devoted to a study of the condition of the internal organs and the bone-support apparatus during the exposure of the organism to abrupt g-forces: the details of the changes in the internal organs under exposure to prolonged radial and angular accelerations; the influence of large and rapid changes in atmospheric pressure on the state of the organs in the pleural cavity and the development of high altitude tissue emphysema in the unprotected parts of the body and means of protecting against it; clarification of the protective role played by G-suits and pressurized suits on the basis of data from x-ray studies.

The monograph is the first roentgenological work in the field of Soviet aviation and space medicine. This has unquestionably increased the difficulty /10
of carrying it out. We will greatfully accept all critical comments and notes from readers and will take them into account.

In conclusion, we would like to express our extreme gratitude to O. G. Gazenko, V. B. Malkin, G. P. Mirolyubov, N. A. Agadzhanyan, A. S. Tsivilashvili and others for their assistance in completing this work.

CHAPTER I. INFLUENCE OF SUDDEN EXPOSURE TO G-FORCES ON THE ORGANISM /13

In conjunction with the very rapid development of aviation and rocket technology, it has become necessary to study the influence of sudden exposure to g-forces on the organism.

Sudden exposure to g-forces arises during emergency exit from the aircraft (ejection and landing), and in spaceflight it is encountered when it is necessary to leave the spacecraft during launching or liftoff, or when landing on Earth. The term "sudden" exposure to g-forces is employed because the organism is subjected to the action of a sharp push, concussion or shock lasting less than 1 second.

Both Soviet and foreign scientists have dealt with the study of the changes that occur in the organism under the influence of brief exposure to g-forces.

The influence of these g-forces on the organism is a function of its physiological state, the magnitude and duration of exposure, the rate of increase, the direction of action with respect to the axis of the body, and the area of the supporting points of the body at the time.

High g-forces are accompanied by considerable deformation of the tissues and displacement of the internal organs, leading to disruption of normal functional activity of the organism. If the limit of strength of the tissues is exceeded, the possibility of their damage cannot be excluded. At very high /14
g-forces, irreversible deformation of the internal organs and bone tissues may occur. The organism is capable of withstanding the highest g-forces when the latter are directed perpendicular to the lengthwise axis of the body (chest--back or back-chest). Therefore certain requirements are imposed on aircraft and systems for protecting the organism (for example, ejection) in order to limit the unfavorable influences of brief exposure to g-forces.

In the Soviet Union, I. D. Kipnis, G. L. Komendantov and others were the first to study the influence of ejection on the organism, using x-ray methods of investigation; they obtained data which are of considerable theoretical and practical importance. In recent years, in conjunction with the conquest of outer space, the interest in this problem has increased enormously.

Soviet investigators have conducted a rather detailed study of the reactions of the cardiovascular system, respiratory organs and central nervous system during ejection.

The first study of the strength of the spine during exposure to dynamic g-forces was conducted by the Russian surgeon A. Ya. Rotenberg (1928, 1939). He performed his research on cadavers. He found that the phsyiological curves of the spine increase its resistance to the action of axial g-forces of high magnitude.

Determination of the mechanical strength of the spinal column using x-rays to study tolerance to g-forces during ejection was first carried out in Germany during World War II. Beckman and Ziegler (1953) point out that in the case of /15
brief exposure to g-forces in the head-feet direction the limit must be considered to be 20 units per 0.1 second with a rate of increase of 200 units per second. Compressive fractures of the vertebrae may occur at high g-forces. Webster and Hunter (1954) found compressive fractures of two vertebrae in pilots following exposure to head-seat g-forces with a magnitude of 20 units.

The materials of Hirsch and Nachemson (1963) are particularly interesting; these researchers studied the x-rays of 55 Swedish pilots who were subjected to the influence of head-seat g-forces with a magnitude up to 20 units. The pilots did not complain of back pains after ejection and neurological examinations failed to reveal any deviations from the norm. However, 14 individuals were found by x-ray examination to have destructive changes, most frequently compressive fractures of the vertebrae. Fracture of one vertebra was observed in only 5 out of the 14 individuals, while the others showed multiple compressive fractures. The lower pelvic vertebrae were the ones most frequently injured.

Cases of spinal fractures following ejection of the subject upward with exposure to g-forces with a magnitude of 9 to 15 units are also known (Gertz, 1944; Lathem, 1957; Cooper, Holmstrom, 1963). Cooper and Holmstrom (1963) found bone damage when the human organism was subjected to g-forces directed in the head-seat direction at a magnitude of 9 units, with a rate of increase of no more than 100 units per second. Fracture of the coccyx was found in 4 out of 200 experiments, cracking was observed in 2 and insignificant trauma, in 5. On the basis of their observations, the authors concluded that the reason for this damage was insufficient elasticity of the seat stuffing and an incorrect posture on the part of the subject.

Data in the literature indicate that there have been cases of rupture of /16
the wall of the aorta during emergency landings of helicopters and aircraft. Hass (1944) and Kiel (1963) feel that one of the principal causes for damage to the vessels is the bending and stretching of the wall as the result of displacement of the heart.

The results of research by foreign scientists have shown that g-forces in the head-seat direction with a magnitude of 18 to 20 units for 0.08-0.12 second with good fixation of the head and hands as a rule do not cause any damage to the spine, while g-forces of more than 20 units can lead to compressive fractures of the spine.

M. P. Brestkin et al. (1962) performed experiments on a great many different kinds of animals: monkeys, dogs, cats and rabbits. As a result of these experiments, they obtained important data that have made it possible to carry out subsequent research involving ejection of human beings with a greater degree of safety. In the majority of experiments involving animals, the g-forces in the head-seat direction reached 12 to 35 units with rate of increase of up to 474 units per second and an exposure time of 0.07 to 0.2 second.

Following the performance of these physiological and clinical observations and x-ray studies, the animals were killed and subjected to pathological anatomical autopsy. Regardless of the fact that the g-forces reached 35 units during ejection, neither x-rays nor autopsy revealed any damage to bones.

The experiments clearly showed the relationship between the damage and the level of the g-forces. Even if the latter did not reach 25 units, the animals could still be found to have bruises of the soft tissues, and some even showed damage to the internal organs. Exposure to g-forces of more than 25 units has been found to result in serious, even critical, damage to the organs of the chest and abdominal cavities as to the brain and spinal cord.

Repeated ejection led to increasingly serious and frequent injury to the animals. It was found that repeated exposure to high g-forces (more than 25 units) produces the most pronounced damage to the lungs, liver, intestines and diaphragm. /17

In studies with human subjects, M. P. Brestkin et al. produced g-forces in the head-seat direction with a magnitude of up to 23 units at a rate of increase of up to 345 units per second for periods of exposure ranging from 0.07 to 0.26 second. The condition of the bone-support apparatus and the internal organs following ejection was examined by means of x-rays. It was found that some of the subjects, even with good immobilization in the seat, felt pressure and transient pain in the chest and abdomen when exposed to g-forces of more than 15 units. X-ray studies and examination by a physician, performed immediately after each ejection, failed to reveal any kind of changes in the organs of the chest and abdominal cavities. It should be pointed out that slight damage to the internal organs or ligamentous apparatus (microtraumas) may not be revealed by these methods of examination. One subject, following exposure to g-forces with a magnitude of 20.3 units was found to have sustained a slight compression of the corpus of the 11th thoracic vertebra.

M. P. Brestkin et al. concluded that at g-forces of up to 20 units and exposures of 0.15-0.2 second the maximum permissible value for the rate of increase is 200 units per second.

As indicated by N. P. Orlov (1966) traumatic injury to the spinal column in crew members is frequently revealed by x-ray studies. This indicates the high level of significance of this method of investigation in aircraft medical expertise. Thus, in 78 out of 365 pilots examined, degenerative-dystrophic changes were found; 10 showed cuneiform deformation of the vertebrae (consequences of compressive fractures) and Bekhterev's disease was found in two. /18

According to the data of N. V. Orlov, traumatic injury to the spinal cord following accidents is diagnosed in time in only 42% of the pilots. The remaining injuries are detected later (after several months or even years) only because of a failure to conduct x-ray examinations in time.

To study the limits of mechanical strength of the vertebrae and the intervertebral discs to compression, S. A. Gozulov et al. (1966) studied

preparations of the spinal column in individuals who had died suddenly and were aged 19 to 70; the elapsed time until the beginning of the experiment was no more than 30 hours after death. A total of 530 tests were performed. Experiments showed that the process of injury usually develops in a certain sequence. Deformation (compression) of the vertebrae relative to their initial height by 12 to 13% caused microscopic irreversible changes in the nature of the compression of the limbic zone, 17-18% — cracks and compression in the area of the waist, 25 to 26% — fractures of the corpora of the vertebrae without displacement of the fractures, 36 to 37% — with displacement, 40 to 50% — fragmentation of the corpora. The strength of the intervertebral discs is slightly greater than that of the vertebrae. The greatest magnitude of elastic deformation is exhibited by the lumbar vertebrae: 1.5-1.9 mm, while the minimum is that of the third through fifth thoracic — 1.1 mm.

On the basis of these studies, S. A. Gozulov et al. established that the most vulnerable area during exposure to brief g-forces is the upper part of the thoracic portion of the spinal column. They also found that the strength of /19
the individual vertebrae is a function of age and individual characteristics. The maximum strength of the axial skeleton was observed between the ages of 19 and 40.

The work of both Soviet and foreign authors has confirmed that resistance to brief exposure to g-forces is influenced by the magnitude, duration and rate of increase, direction, conditions governing the system of immobilization in the seat and the state of physical development. This indicates that particular attention should be paid to those prophylactic measures which can ease the force of the shock.

At the present time, both Soviet and foreign scientists are recommending the extensive introduction in aviation and space field of capsules and separable cabins. The considerable importance of using separable cabins which make it possible to eject at any altitude was pointed out by P. K. Isakov (1962), Roxburgh (1961) and others.

Ejecting from an aircraft in a separable cabin has a number of important advantages — total protection against the influence of the head wind, unfavorable high altitude factors, etc., so that it is not necessary to use a special protective clothing (pressurized suits, g-suits, etc.).

At the present time, the most rational method of protecting the organism against the influence of brief exposures to g-forces involved in landing is the use of shock absorbing devices which make it possible for the crew to land directly in the separable cabin (G. P. Mirolyubov, 1963).

The separable cabin may be used effectively regardless of the speed, /20
altitude and range of flight.

The first experimental studies of the influence of exposure to brief g-forces that arise during the landing of a separable cabin and the possibilities of increasing the resistance of the organism to them were conducted by P. K. Isakov, G. P. Mirolyubov, S. A. Gozulov et al. (1960, 1964).

Abroad, work dealing with the study of the conditions of landings by human beings in a cabin have been published since 1960. Swearingen et al. (1960) published results of a study of the tolerance of human beings to g-forces produced by falling in a chair at the rate of 1.5 m per second. Brinkly (1960) performed experiments to study the influence of g-forces created by landing in a Mercury spacecraft capsule and means of protecting human beings against their effects. They used a honeycomb shock absorber to reduce the impact of landing on the ground.

The landing of the cabin is also accompanied by exposure to the action of brief g-forces. Depending on the rate of descent and the density of the ground, they can reach values which cause damage to the organism.

The g-forces that arise when the cabin lands differ in their parameters from g-forces created by ejection. Thus, the landing of a cabin at a rate of 9 to 10 m per second is accompanied by g-forces of 50-100 units or more as a function of the density of the ground. The orientation of the cabin in space is not constant during the landing (swaying on the parachute shrouds, lateral transport by the wind, etc.) and consequently the g-force vector may differ in direction.

The g-forces that arise in transportation accidents, rough landings by aircraft, accidents associated with the fall of human beings from an altitude, etc. are similar in characteristics to g-forces caused by landings. /21

Haven (1942) presents an analysis of several cases in which individuals fell from an altitude of 15 to 50 m to the ground, with the latter being of different degrees of density (from friable soil to a metal beam) with comparatively slight injuries and sometimes with none. The magnitude of the g-forces then reached 100 to 200 units. He concludes that under certain conditions man can withstand unharmed much greater g-forces than have previously been established in experiments.

The posture of the individual and his correct restraint by straps increase his resistance and ability to withstand g-forces (Poppen, 1958 et al.).

Hence, g-forces associated with landing in a separable cabin are characterized by a high value, shock duration and rapid rate of increase. Therefore, their influence on the organism may lead to serious traumatic damage to the bone system and the internal organs. In this connection, considerable significance is attached to increasing the resistance of the organism to the action of brief g-forces.

Characteristics of the Method of Investigation Using Animals

The influence of brief exposure to g-forces on the organism during landing has been studied using white rats and dogs. 89 experiments were performed on 75 animals (39 experiments on 29 dogs and 50 experiments on 46 rats).

The g-forces, ranging in magnitude from 50 to 1,000 units in the head--pelvis and back-chest direction, were produced on special stands with a rate of descent from 2 to 13 m a second. The rats were subjected to the influence of brief exposures to g-forces without protective methods being employed. The studies on dogs were conducted in two series of experiments: in the first, the /22
influence of brief exposures to g-forces on the animal organism were studied without the use of any protective devices, while in the second such devices were employed.

The animals were subjected to roentgenography of the organs of the chest cavity and the skeletal system, as well as roentgenokymography of the heart, large vessels and diaphragm prior to the experiment, 10 to 40 minutes after its termination and subsequently every 24 hours for 10 to 12 days, after which the animals were sacrificed and subjected to morphological examination.

The rats were subjected to the influence of brief exposures to g-forces in the back-chest direction with a magnitude from 50 to 800 units for 0.00864--0.00117 second. As a result, various functional and morphological changes were observed. Their degree and nature bore a direct relationship to the magnitude of the g-forces. At low values (up to 100 units) slight reversible changes were found in the organs of the chest cavity (an increase in the filling of the lungs with blood, a slight increase in the size of the heart), while at high values there were significant functional and morphological changes both in the organs of the chest cavity and in the skeletal system (acute peripheral emphysema, hemorrhaging and atelectases in the lungs, pneumohemothorax, enlargement of the heart, fractures of the ribs and bones of the pelvis).

It should be pointed out that the development of pneumohemothorax was observed in the rats under the influence of g-forces of more than 220 units of magnitude and the fractures were observed at more than 600 units.

In the first series of experiments on dogs (without protective devices) the g-forces in the head-pelvis direction reached levels of 200-1,000 units in 0.002 second and in the back-chest direction, 67 to 320 units in 0.02-0.0045 second.

An analysis of the roentgenological data that was obtained revealed that /23
when brief exposures to g-forces of high magnitude were imposed on the organism, significant injury resulted to the internal organs and the bone system: stagnation phenomena in the lesser circulation, atelectases and hemorrhages in the lungs, compressive fractures of the vertebrae, etc. The data are shown in Table 1.

As we can see from Table 1, under the influence of g-forces in the head-seat direction imposed on the organism without the use of protective devices, there was damage to the spine in all cases, most frequently in its lower segments. As the brief exposure to g-forces increased, the fractures occurred in the following sequence: caudal vertebrae at the base, lumbar, lower thoracic vertebrae and bones of the pelvis. At high levels of g-forces more pronounced injury was found in the bone-support apparatus: numerous fractures of the

vertebrae (Figure 1). The degree and nature of the changes in the organs in dogs depended on the magnitude of the g-forces.

In the case of g-forces in the back-chest direction 67 to 93 units in magnitude for 0.0022-0.014 seconds there were insignificant functional reversible changes in the organs of the chest cavity; there was an increase in the picture in the caudal areas of the lungs and a slight increase in the air capacity of the caudal-lateral segments of the lungs.

Exposure to g-forces with a magnitude of 113-160 units for 0.009-0.011 second revealed visible morphological changes in the organs of the chest cavity. They were especially clearly evident in the roentgenological picture of the lungs: markedly pronounced diffuse intensification of the pulmonary picture, peripheral emphysema and slightly intensive focal shadows in the lungs. These foci merged in some places.

TABLE 1. NATURE OF THE CHANGES AS THE FUNCTION OF THE WEIGHT AND HEIGHT OF FALL OF THE ANIMAL /24

Name of dog	Weight in kg.	Height of fall, m	Results of Investigations	
			Roentgenological	Morphological
1	2	3	4	5
Volchok	10.5	5.5	Intensification of the pulmonary picture, increased transparency of the lungs, significant decrease in size and intensity of heart shadow, transverse fracture of the 5th sacral vertebra with displacement of the peripheral bone fragment	—
Volchok	10.3	8.5	Considerable increase in the lung picture. Small areas of darkness in the central field of the right lung. Pronounced decrease in size and intensity of heart shadow. Numerous vertebral fractures: compressive fracture of the corpus of the 10th thoracic vertebra with significant destruction of its anterior portion, partial damage to the corpora of the 8th and 9th thoracic vertebrae,	Hemorrhages in the kidneys, lungs with areas of atelectasis. Rupture of the liver. Breakage of the spinal cord at the level of the 9th thoracic vertebra.

TABLE 1. CONT'D.

1	2	3	4	5
			transverse fractures of the spinal processes of the 8th, 9th and 10th thoracic vertebrae, fragmentary fractures in the area of the lumbar-sacral vertebrae with displacement of bone fragments.	
Ryzhaya	7.55	6.0	Intensification of the pulmonary picture, individual small areas of darkness in the left lung, decrease in the size of the heart shadow. Fragmentary fracture of the lower third of the 6th lumbar vertebra with considerable displacement of bone fragments.	Breakage of the spinal cord in the vicinity of the 6th and 7th lumbar vertebrae. Rupture of the kidney capsules. /25
Rex	9.2	5.0	Slight intensification of pulmonary picture in the upper areas of the lungs. Breathing shallow. Heart size increased. Small, scarcely visible serrations along the edges of its shadows. In the x-ray 3 hours after the experiment, the heart shows no changes with respect to normal. Compressive-fragmentary fracture of the 11th thoracic thoracic vertebra and partial compressive fracture of the 10th thoracic vertebra. Fragmentary fractures of the 5th sacral vertebra and left ischium.	Spinal cord separated by hematoma. Posterior horns fused. Lungs with areas of atelectases. Torn wounds in the liver. Streaks of blood in the gastric cavity.
Lisa	6.85	4.0	Against the background of an increased pulmonary picture, individual small areas of darkness. Heart shadow slightly decreased. Compressive fracture of the lower third of the corpus of	Lungs and liver without visible damage. Extensive hemorrhage retropritoneally in the vicinity of the sacrum.

TABLE 1. CONT'D.

1	2	3	4	5
			the 6th lumbar and the upper third of the 1st sacral vertebra.	
Zhuchka	9.9	4.0	Intensified pulmonary picture, individual small foci of darkness in the upper areas of the lungs. A slowing of the respiratory rhythm with difficulty in exhaling. Size of heart shadow reduced. Transverse fracture of the 5th sacral vertebra with slight displacement of the peripheral bone fragment. Transverse fracture of the corpus of the 5th caudal ossicle.	—
Knopka	7.75	3.0	Slight increase in pulmonary picture. No other changes visible in the lungs. Heart without significant changes. Transverse fracture of the third caudal ossicle without displacement of the bone fragments.	—
Belka	7.3	2.0	Insignificant increase in pulmonary picture. Slowing of respiration with difficulty in exhalation. Heart shadow without significant changes. Compressive fracture of the 6th lumbar vertebra.	
Kama	12.0	2.0	Transverse fracture of the 5th sacral vertebra.	—

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Dynamic x-ray observation of the organs of the chest cavity in these animals for 1 to 2 days following the end of the experiment revealed a further increase in the pathological process. While changes in the lungs were of a limited nature immediately after the experiment, subsequently the lung areas were seen to have dense cloud-like shadows as the result of posttraumatic changes in the lungs. /28

Figure 1. Lateral X-ray of Lumbo-sacral Vertebrae of the Dog Ryzha Following Exposure to G-forces in the Head-Pelvis Direction. Animal thrown from a height of 6 m with no protective devices being employed. Fragmentary fracture of the lower third of the corpus of the 6th lumbar vertebra with significant displacement of the peripheral bone fragments. Spinal column completely broken.

To illustrate the changes mentioned above in the x-ray picture of the organs of the chest cavity, let us examine Figures 2-4.

Under the influence of g-forces with a magnitude of 195-320 units for 0.0045-0.0074 seconds, in the majority of cases there was a development of significant morphological changes in the organs of the chest cavity: spreading cloud-like shadows over almost the entire area of both lungs with symptoms of peripheral emphysema and, as a rule, enlargement of the heart shadow. Observations under dynamic conditions revealed a further increase in the changes indicated.

It should be mentioned that in the x-rays that were obtained in experiments with dogs, no bone injuries were observed.

In the second series of experiments on the influence of g-forces in a head--pelvis direction on dogs, various protective devices were employed. /29

In examining the x-ray material obtained during the action of overloads under conditions of emerging the animals in water, a characteristic feature is the total absence of damage to the bone-support apparatus and highly significant damage to the pulmonary tissue (Table 2).

It is clear from Table 2 that under these conditions massive hemorrhages and atelectases occur in the lungs, and there are also significant changes in the heart.

To illustrate the above changes in the roentgenological picture of the organs of the chest cavity, let us examine Figures 5 to 6.

The roentgenokymograms of the diaphragm and ribs (following the end of the experiments) revealed considerable changes in the functional condition, taking the form of a flowing of the respiratory rhythm with increasing difficulty in the expiratory phase. The death of the dog ensued 12 hours after the experiment.

TABLE 2. NATURE OF INJURIES PRODUCED BY THE ACTION OF G-FORCES UNDER CONDITIONS WHICH THE ANIMALS WERE SUBMERGED IN WATER. /32

Name of dog	Weight in kg	Height in fall, m	Results of Investigations	
			Roentgenological	Morphological
Pestraya	11.85	11.5	Both lungs show dense spreading cloud-like shadows and numerous small areas of transparency. Heart shadow deformed, irregular rounded shape.	Extensive hemorrhages in the lungs. Edema in the latter. Point hemorrhages into the substance of the brain, mucous membrane of the stomach, intestine.
Damra	8.4	7.0	Dense spreading cloud-like shadows in both lungs and numerous small areas of transparency. Heart shadow slightly deformed. Irregular shape.	Extensive hemorrhages in the lungs. Edema in the latter. Rupture of the liver. Air emboli in the arteries of the brain and heart.
Zhuchka	8.4	4.0	Both lungs show dense spreading cloud-like shadows and numerous small areas of transparency. Heart shadow deformed, irregular rounded shape.	Extensive hemorrhages in the lungs. Air emboli in the arteries of the heart, brain and intracostals.
Mal'va	6.6	6.0	Dense spreading cloud-like shadows and numerous small areas of transparency in both lungs. Respiration speeded up and shallower. Size of heart shadow reduced only small scarcely noticeable serrations on its edge.	Lungs edematous with areas of hemorrhaging. Perforation of the large intestine.

Figure 2. X-ray of Organs in the Chest Cavity of the Dog Mukha Before the Experiment.

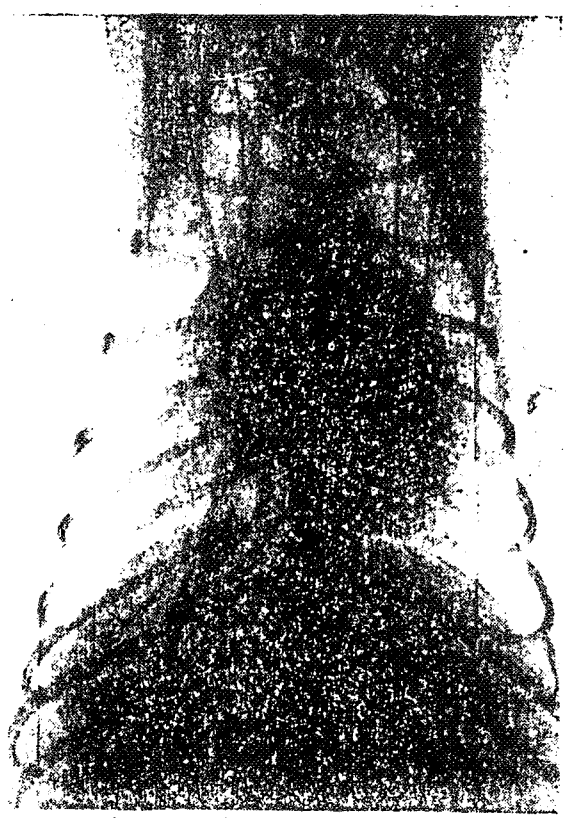

Figure 3. X-ray of the Organs of the Chest Cavity of the Same Dog, 40 Minutes Following Exposure to Brief G-forces in the Back-Chest Direction, with a Magnitude of 160 Units for 0.009 Second. No protective measures were taken. There was an increase in the transparency of the peripheral areas of the lungs, a diffuse increase in the pulmonary picture with presence of numerous scattered low-intensity finely focused shadows. /29. 30

The results of the morphological studies were as follows: in the chambers of the heart, especially the right heart, there were many dark red friable clots of blood; the coronary vessels were overfilled with dark blood. The heart muscle was dense and bluish. The lungs were enlarged, dark red, only the apical and right heart areas (boundary sections) were colored a pale pink. The lung tissue was compacted, and section revealed a great deal of foamy blood stained fluid. The same fluid filled the trachea and bronchi.

Microscopic examination of the lungs revealed the following: acute alveolar emphysema, the lumina of several alveoli and alveolar pathways were markedly dilated, elastic fibers in the latter were very elongated and in some places even fragmented. Ruptures in the interalveolar septa were visible, with extensive areas of hemorrhaging and edema. The lumina of the pulmonary veins

were dilated, filled with blood, and in some cases there was a complete breakage of the entire thickness of the wall; such vessels showed circular hemorrhages around them. The lumina of the bronchi were dilated; filled with edematous fluid or blood.

Thus, the lungs showed massive spreading cloud-like shadows and numerous small rounded areas of transparency indicating edema and atelctasis of the lungs, hemorrhages of the pulmonary tissues and focal emphysema.

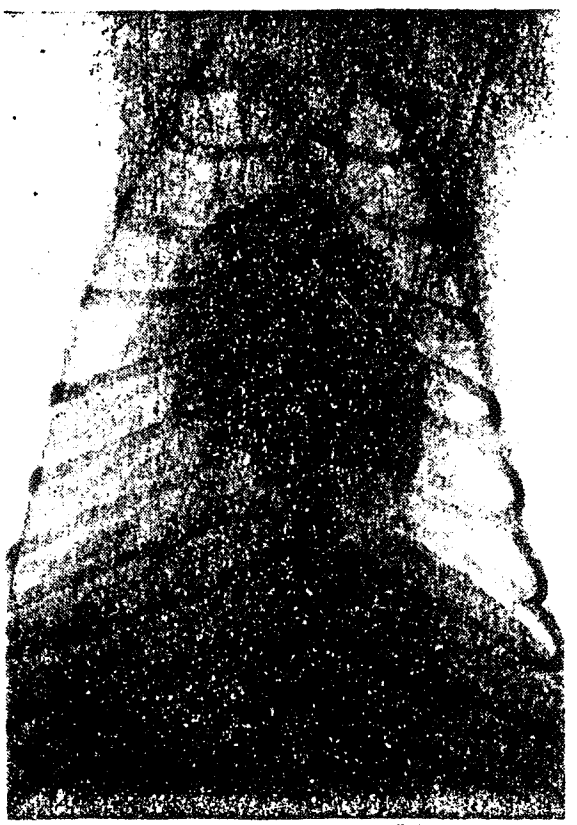

Figure 4. X-ray Organs of the Chest Cavity of the Same Dog, 24 Hours Following the End of Exposure to Brief G-forces. In the caudal portion of the right lung, beginning with the 5th intracostal from the front, there is an extensive cloud--like shadow whose cranial edge is clear and even. In other areas of the lungs there are scattered low intensity fine focused shadows. The reason for these changes can be found in hemorrhages and atelectasis in the lungs.

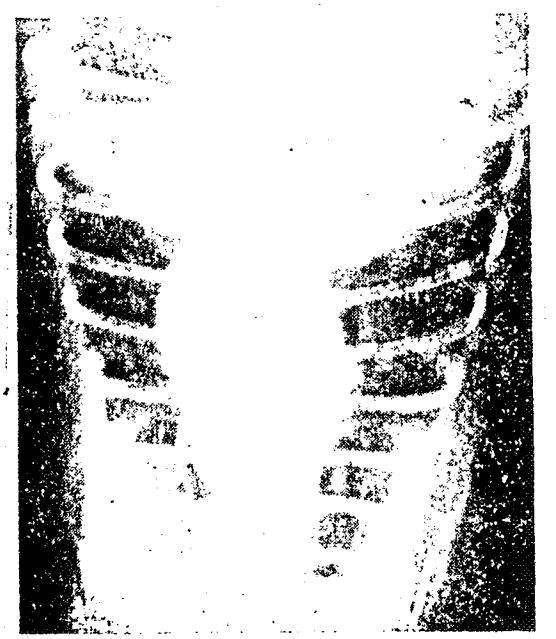

Figure 5. Direct Roentgenogram of Organs in the Chest Cavity of the Dog Mal'va Prior to the Experiment. /34

It is to be pointed out that under the influence of brief g-forces in the head-pelvis direction on the organism, using protective measures in the form of submersion of the body in water, none of the animals developed traumatic changes in the bone system. /31

The results of the x-ray studies of the animals following exposure to sudden g-forces with the use of additional protection are shown in Table 3. /35

Figure 6. Roentgenogram of the Organs in the Chest Cavity of the Dog Mal'va 30 Minutes Following the End of the Experiment, With the G-forces Being Applied in the Head-Pelvis Direction. The animal was thrown in water from an altitude of 6 m. On the roentgenogram, both lungs show dense spreading cloud-like shadows and numerous rounded areas of transparency (hemorrhages and focal emphysema). Heart size decreased.

It is clear from Table 3 that under these conditions there were only slight reversible changes in the lesser circulation (stagnation phenomena in the pulmonary vessels).

Interesting data were obtained /36
on the behavior of the dynamic roentgenological behavior for 3 dogs that were subjected to the influence of brief exposure to g-forces using protective devices. In these experiments, one can see the high protective effectiveness of the means that were employed. In the roentgenograms that were taken 15 to 45 minutes after the experiment, there is only a slight increase in the pulmonary picture, heart size, shape and position of the latter remaining essentially unchanged; 1 to 2 days later, the upper areas of the lungs showed individual small areas of darkness which later disappeared.

Hence, the results of the roentgenological studies that had been performed dealing with the action of briefly applied g-forces in the head-pelvis and back-chest direction have made it possible to detect a number of changes in the internal organs and bone system. Compressive fractures of the vertebrae, stagnation phenomena in the lesser circulation, hemorrhages, edema and atelectasis in the pulmonary tissue, emphysema of the lungs, pneumothorax, etc. were all observed.

The nature and the degree of the changes caused by sudden exposures to g-forces applied in various directions were assorted. While the action of g-forces in the head-pelvis direction led to increased bone damage, beginning at 200 units, after which there were morphological changes in the internal organs beginning at 300 units, exposure to g-forces in the back-chest direction led to an earlier detection of morphological changes in the internal organs, beginning at 113 units and then leading to bone damage which could be detected at 600 units (Table 4).

TABLE 3. NATURE OF CHANGES AS A FUNCTION OF WEIGHT, HEIGHT OF FALL AND CONDITIONS OF RESTRAINT. /37

Name of dog	Weight in kg.	Height of fall, m	Conditions of Restraint	Results of Investigations	
				Roentgenological	Morphological
Knopka	7.4	5	Tightly bound with bandages	Increase in pulmonary picture. Heart without significant changes	—
Krasavchik	7.4	8	Restrained in a cylindrical holder.	Increase in pulmonary picture and increased transparency of the lungs. Heart without significant changes.	—
Marta	9.1	8	Container lined with sponge rubber	Slight increase in pulmonary picture. Heart without significant changes.	—
Marta	9.0	8	In pressurized jacket	Slight increase in pulmonary picture. Slight area of darkening in the upper area of the right lung. Heart without significant changes.	
Snap	7.5	8	Wrapped in foam rubber	Cloud-like shadows in both lungs. Heart shadow deformed, irregular rounded shape.	Hemorrhages in the lungs.
Knopka	7.4	12	Tightly bound with bandages	Individual small areas of darkness visible against the background of increased pulmonary picture. Size of heart shadow slightly decreased.	—

/38

The nature of the damage to the internal organs indicates that the disruptive force under these conditions is both the hydrodynamic shock to the internal organs and the pressure drop in the hollow organs, which is accompanied by displacement and deformation of the organs and the tissues. This assumption is confirmed by the fact that similar ruptures with damage to the vessels and hemorrhages into the tissues occur on exposure to a shock wave in air (I. S. Beritov et al., 1945; B. V. Nifontov, 1957 et al.) and during changes in barometric pressure as a result of a sharp increase in air pressure in the lungs (S. A. Tsivilashvili, 1963 et al.).

The mechanism of the disruption of the activity of the heart still remains rather unclear and is probably caused by the direct traumatic action of the abrupt exposure to the g-force and by the disruption of circulation in the lesser circulation and damage to the lungs.

Less frequent damage to the other internal organs, as indicated by M. I. Kas'yanov and G. P. Mirolyubov (1965) during sudden exposure to g-forces is explained obviously not only by the characteristics of the structure of the tissues but by the arrangement, fixation of the ligamentous apparatus and other anatomical features.

As a result of the physiological-x-ray studies, it was established that there is a possibility of protecting the organism against the harmful effects of sudden application of g-forces. When a plaster bed is used and the animal /40
is submerged in water in a pressurized jacket, no bone injuries or significant changes in the organs of the chest cavity were observed even under the influence of brief exposure to g-forces measuring 600 to 1,000 units. The insignificant changes that arise under these conditions are found primarily in the lungs and are reversible in nature.

Submersion in the water slightly increases the resistance of the animals to the action of g-forces. It should be pointed out that while no bone damage is sustained under these conditions, the changes in the organs of the chest cavity were revealed by x-rays were significant and often led to the death of the animals.

Characteristics of a Method of Investigation With Human Participation

Forty-three men aged 20 to 35 took part in the studies; they had been selected by a medical-flight commission as suitable for experiments on the effect of sudden exposure to g-forces.

The subjects were repeatedly subjected to the action of sudden exposure to g-forces applied in the head-feet and chest-back direction for 3 years, with a value of up to 29.6 units, on special stands using protective measures.

X-rays of the organs and the chest cavity and spine were taken before and after the end of the experiment.

TABLE 4. NATURE OF THE CHANGES IN THE ANIMAL ORGANISM FOLLOWING SUDDEN EXPOSURE TO G-FORCES. /39

Direction and Magnitude of the Application of the G-forces	Total number of experiments	No. of animals with changes in organs	Increase in filling of the pulmonary vessels with blood	Atelectasis and hemorrhages in the lungs	Atelectasis and hemorrhages in the lungs and changes in the heart	Spinal fractures	Fractures of ribs and bones of the pelvis
Without protection:							
Head-pelvis							
200 - 300 units	3	3	3	-	-	3	-
300 units and more	6	6	-	6	-	6	-
Back-chest							
50 - 100 units	22	22	11	6	5	-	-
100 - 600 units	38	38	-	5	33	-	-
600 units and more	10	10	-	-	10	-	5
With protection:							
Head-pelvis with submersion in water							
300 units and more	5	5	-	-	5	-	-
In an inflated pressurized jacket and submersion in water							
300 units and more	2	2	2	-	-	-	-
With wrapping of the animal's body in a gypsum mold							
300 units or more	3	3	3	-	-	-	-

There are some unfavorable factors in the environment (pressure drop, shocks, g-forces, etc.) acting on the organism, cause definite changes involving the cardiovascular system, the respiratory organs and the bone-support apparatus. By examining the nature of the roentgenological changes, one can get some idea of the general condition of the organism following exposure to a given factor.

Studies were conducted in 2 series: in the first, the immediate consequences of exposure of the organism to sudden exposure to g-forces, produced under laboratory conditions, were studied, while in the second the remote consequences of the g-forces produced by landing with a parachute were studied. /41

The immediate consequences of the action of brief exposure to g-forces on the organism, produced under laboratory conditions. Prior to exposure to the g-forces, 25 out of the 43 subjects were examined roentgenologically and failed to reveal any noticeable changes in the spine. The other 18 individuals showed slight deviations: 9 had slight symptoms of scoliosis and incomplete bony fusion of the arches of the first and second sacral vertebrae, 3 showed complete or incomplete lumbarization of the first sacral vertebra, one showed incomplete sacralization of the fifth lumbar vertebra and 5 showed uneven development of the transverse processes of the fifth lumbar vertebra.

On the basis of a dynamic roentgenological examination it was established in the course of the experiments that the purpose of these deviations in the development of the bone structure are not a counterindication for carrying out work that has to do with exposure of the organism to brief periods of subjection to g-forces.

Results of the study of these series of experiments revealed that while the subjects showed no visible pathological changes as far as the organs of the chest cavity were concerned following multiple exposure to g-forces (head--pelvis, 7-29.6 units and head-back, 9.6-27.4 units for 0.08-0.2 second up to 10-11 times over 2-3 years), 2 did show slight damage involving the spine. The reason for this damage to the spine may have been in particular failure to observe the rules for ejection (changing the correct pose, restraint, etc.).

In this connection, mention should be made of the case which was described by M. P. Brestkin et al. (1962) who observed compression of the 11th thoracic vertebra at a g-force of 20.3 units only once (164 ejections). Motion picture photography established that at the time of exposure to g-forces the subject had removed his hand from the rail and his trunk was tilted to the right. In this position of the body, the shock absorbing properties of the spinal column are reduced, so that fracture occurred. It is completely possible that the same situation could have occurred in our subject. /42

Remote Consequences of G-forces Associated with Landing With a Parachute. According to the data in the literature, in most cases parachute jumps are followed by sprains, dislocations and fractures of the bones of the legs and arms. There are little data in the literature, which indicate damage to the spine. Only certain researchers briefly mention compressive fractures as rare exceptions (A. G. Karavanov, 1946; A. P. Alekseyev, 1957, etc.). Work by

G. L. Komendantov et al. (1962) mentions that student parachutists may suffer residual deformations of the spine as a result of numerous jumps under rugged conditions. Hence, it is part of the physician's responsibility to carry out x-ray studies of parachutists.

As the results of our studies revealed, data on injury to the spine may be lacking because of insufficient x-ray examination of parachutists. In this connection, our study is of considerable theoretical and practical interest

An x-ray examination was conducted of the 10 parachutists aged 23 to 35, who had made 2 — 2218 jumps over the course of 2 to 18 years from altitudes of 800 to 14,500 m.

The results of the x-rays studies revealed that in most of the parachutists /43
(8 out of 10) there were various changes in the spine: cunieform deformation of the lower thoracic or upper lumbar vertebrae, with phenomena of degenerative changes in the intervertebral discs (in 4), peripheral bony processes on the corpora of the thoracic or lumbar vertebrae (in 3) and fracture of the bony process of the 7th cervical vertebra (in 1).

It should be pointed out that these changes in the spinal column were not noted by anyone earlier and the parachutists continued to jump. They were erroneously diagnosed as having bruises of the spine and chest cavity, myositis, etc.

To illustrate the changes observed, several x-rays of the spine have been provided (Figures 7 and 8). None of the parachutists showed visible pathological changes in the organs of the chest cavity.

The data from roentgenological studies allow us to conclude that the bony processes that developed on the corpora of the vertebrae, their cuneiform deformation with signs of degenerative changes in the intervertebral discs and the fractures of the bony processes, are all the results of trauma following the jumps that were made. This indicates the necessity for carrying out a clinical--x-ray check of parachutists for purposes of timely diagnosis, as well as adoption of protective and therapeutic measures.

The results of studies involving participation of human subjects revealed that numerous exposures of the organism to brief g-forces in the head-pelvis direction with a magnitude of 18.2-22.8 units for 0.2-0.08 second may cause damage to the spine in the form of compressive fractures. The traumatic effect depends on the parameters of the brief exposure to the g-forces, the conditions of its action on the organism, and several anatomical-functional characteristics of the organs and tissues of the body. The results of our studies are in agreement with the data of other authors (M. P. Brestkin et al., 1962, and others).

Figure 7. Lateral Roentgenogram of Thoracic Vertebrae of Parachutist M. The x-ray shows a slight decrease in the height of the anterior portions of the 8th-9th and 11th-12th thoracic vertebrae, peripheral bony processes on the corpora of 9 and 10.

Figure 8. Lateral X-ray of Cervical Vertebrae of Parachutist M. There is a separation of the apex of the bony process of the 8th cervical vertebra.

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CHAPTER II. INFLUENCE OF PROLONGED G-FORCES AND ANGULAR ACCELERATIONS ON THE ORGANISM /49

Acceleration is one of the important dynamic flight factors. It arises when the speed or direction of flight are changed. Acceleration is usually expressed in m/sec^2 or as a multiple of the speed of a body falling freely to the ground in 1 second, equal to 9.81 m/sec^2, and represented by the letter "g".

In flights aboard aircraft, prolonged accelerations arise when performing stunting; aboard spacecraft, they occur when the spacecraft is launched into orbit and lands on the ground.

Soviet literature frequently uses another term "peregruzka" (overload) as well as the term "uskoreniye" (acceleration); the former, usually translated as "g-force", more correctly reflects the true meaning of the events taking place and is convenient for analyzing the changes observed in the organism.

A coefficient which shows how many times the acceleration of a body is greater than the force of gravity, or the force acting on the individual is greater than his own weight, is used to express quantitatively the idea of g-forces. G-forces are always directed opposite to the acceleration vector.

We studied the nature of roentgenological changes in the organs of the chest cavity during exposure of the organism to prolonged g-forces and angular acceleration.

The state of the organism under the influence of g-forces is a function of /50
a number of factors, the most important of which are magnitude, duration, rate of increase and direction of application of g-force relative to the trunk, as well as the original functional state of the organism. The influence of g-forces may lead to the development of functional and morphological changes in the organs of the respiratory, cardiovascular, nervous and other systems.

Influence of G-Forces in the Head-Feet Direction

Many Soviet and foreign scientists have studied the problem of acceleration.

The earliest studies, conducted for the purpose of investigating the regulation of circulation of the blood and evaluating the role of terrestrial gravitation, may be found in Russian literature in the works of N. O. Tsibul'skiy (1879), V. V. Pashutin (1881), V. P. Kuznetsov (1888), Kh. Sh. Borishpol'skiy (1896) and others, who performed experiments on animals to study problems related mainly to changes in hemodynamics. The significance of the results consists in the fact that they were performed by the authors with a knowledge of the considerable importance of the activity of the central nervous system in the regulation of blood circulation. The results of the research of N. O. Tsibul'skiy and V. A. Pashutin were confirmed in much later works by other authors, who performed experiments on animals (rabbits and cats) with the afferent

pathways severed (M. D. Chirkin and O. A. Balandina, 1943; A. A. Sergeyev, 1951).

The first work dealing with the study of problems of aerial navigation and cosmonautics is attributed to K. E. Tsiolkovskiy (1912). Even in those days, the author was working on a search for methods of increasing the resistance of the organism to g-forces. He felt, for example, that keeping the organism in a liquid medium might be a highly effective protective measure against the /51
action of g-forces. In addition, taking into account the capacity of the organism, K. E. Tsiolkovskiy said that the resistance of man to the action of this factor is not unlimited even under conditions of application of protective measures.

In 1930-1935, Soviet aviation began to develop rapidly; this development was accompanied by a steadily increasing interest devoted to problems of investigating the action of g-forces on the human organism. Scientists obtained important data on the influence of g-forces on the human organism under flight conditions. I. Ya. Borshchevskiy et al. (1938) found that brief (1 second long) exposure to g-forces with a magnitude of 7-8 units in the head-feet direction caused pilots to complain of blackouts. The authors considered this to be the direct result of an incipient disturbance of the blood circulation to the brain.

Many of the papers by V. V. Strel'tsov were devoted to a study of the influence of g-forces on the organism. The author devoted particular attention to those changes which arise in the circulatory system. On the basis of his observations (1938), he felt that the primary determining factor which limits the tolerance of the organism to g-forces is a change in this system. In his opinion, they cause primarily a disruption of the blood supply to the central nervous system, especially the organs of vision.

Many authors also viewed changes in the circulatory system as the principal cause leading to various disturbances of the functional activity of the organism under conditions of exposure to g-forces.

I. M. Khazen (1958), P. M. Suvorov (1958) and others have studied the /52
influence of radial accelerations on the functional activity of the organs of the digestive tract. They established the role of the neuroendocrine system in the regulation of physiological functions of the organism and discovered pathways which lead to an increase in the resistance of the organism to g-forces. The results obtained by these authors may be employed in developing physiologically based rational modes of feeding pilots.

G. L. Komendantov (1953, 1956), V. M. Savin (1952, 1953, 1966) and others interpret the mechanism of the influence of g-forces on the organism differently. They feel that the development of functional disturbances, and consequently the decrease in the working capacity in pilots during exposure of the organism to g-forces, occurs as a result of the unfavorable influence of unusual afferent impulsation, originating in the tissues and organs which are subjected to displacement and deformation. These nerve impulses, reaching the

central nervous system, cause various types of phenomena to develop in it: irradiation of the excitation process, external inhibition by means of a mechanism of negative induction, and external inhibition within individual nerve cells, which leads to an inhibition of the function of the compensatory mechanisms of the organism, including those of the cardiovascular system. As a result, in the opinion of these authors, the blood pressure in the vessels of the brain is not maintained at the required level and functional disturbances begin to develop until the individual faints.

We decided to study in greater detail those works in which methods of x-ray investigation were employed.

Jongbloed and Novons (1933), studying the influence of g-forces on the organism, were the first to use the roentgenographic method. In experiments on unanesthetized rabbits the authors observed that exposure to g-forces with a magnitude of 3-3.5 units led to a significant decrease in heart size and also caused transparency of its shadow. This phenomenon was explained by these authors as being due to a decrease in the filling of the heart with blood. Under the influence of g-forces with a magnitude of 1.5-2 units in the head--pelvis direction, a decrease in the blood pressure in the carotid artery and an increase in the femoral artery were noted; at g-forces of 3-3.5 units, the blood pressure in the carotid artery fell almost to zero in some animals. The authors felt that the critical factor in the action of g-forces on the organism was disruption of the circulatory system.

The principal shortcoming of this work, in our opinion, is the incorrect choice of experimental animals, inasmuch as it is known that rabbits, because of the nature of their regulation of the cardiovascular system, are not very resistant to the action of g-forces (D. Ye. Rozenblyum, 1939; A. A. Sergeyev, 1951 and others).

A great many studies of the influence of g-forces on the human organism were conducted by Diringshofen. A great number of them was performed under conditions of special experimental flights. The author devoted principal attention to the study of the changes in the circulatory system.

In evaluating the data which he obtained, the author (1932) pointed out that the physiological effect of the action of g-forces on the organism takes the form primarily of changes in hemodynamics. He notes the presence of a direct relationship between the arterial pressure values and the g-forces.

Diringshofen concludes that the resistance of the organism to the action /54
of g-forces is solely a function of changes in the value of the hydrostatic pressure in the "heart-brain" segment of the circulatory system and as a result of the influence of g-forces on the organism may be determined in advance by means of an appropriate mathematical formula.

The invalidity of this view was demonstrated by the author himself in later works. Thus, in a paper which appeared in 1942, he stated that some of the pilots which he had studied displayed considerable resistance to the action

of g-forces. During brief exposure to the action of g-forces with a magnitude of 7 units or more applied in the head-feet direction, these pilots failed to show any signs of disruption of vision or loss of consciousness. Apparently a compensatory increase in blood pressure occurred in them under the influence of their accelerations.

In this same paper the author presented data from x-ray investigations. X-rays of the organs in the chest cavity taken during exposure to g-forces with a magnitude of 6-7 units revealed only slight symptoms of changes in the heart shadow, indicating a slight decrease in the filling of the heart with blood. Similar roentgenological data were recorded for subjects with disruption of vision.

X-rays taken during acute vascular insufficiency (collapse) showed a marked decrease in the size and intensity of the heart shadow, which can only be linked to a decrease in its filling with blood.

Roentgenological methods of investigation were employed to study the influence of g-forces in the organism by the following authors: Fischer (1937), Peiffer (1939), Gauer (1944, 1950), Hershgold (1960), Mueller (1961) and Sandler (1966).

Gauer (1944), using the x-ray cinematographic method of investigation in /55
experiments on lightly anesthetized monkeys and cats, demonstrated that the changes in the organism vary as a function of the magnitude of the acting g-force. If the g-force does not exceed 2 to 3 units, the heart retains a nearly normal configuration and only a slight displacement of the organ in the caudal direction is noted. A marked diffuse increase in the transparency of the cranial portions of the lungs occurs, while their caudal portions, on the other hand, acquire an intensified picture resembling that of stagnation phenomena in the vessels of the lesser circulation. However, if the level of the g-forces reaches 6 units, the animals suffer acute changes not only in the configuration of the organs but in their positions in the chest cavity. The dimensions of the heart are then markedly reduced and changes in the picture of the lungs become still more pronounced.

Gauer established that even under the influence of g-forces of 5.5 units the stroke volume of the heart remains high regardless of the considerable reduction that occurs in its dimensions. He concluded that the direct cause of the development of changes in the lung picture is the disruption of the hemodynamics in the lesser circulation.

Hence, studies using x-ray methods reveal a decrease in the size and intensity of the heart shadow with increasing magnitude and duration of exposure to g-forces. This phenomenon is associated with a decrease in the filling of the heart with blood due to displacement of the latter from the upper half of the body into the lower half.

A significant shortcoming of the above mentioned papers, in our opinion, is the fact that the research, with the exception of the experiments of

Jongbloed and Novons, were performed using anesthesia and the data were not compared with data in experiments with unanesthetized animals. /56

The research conducted by Jasper and Cipriani (1945) is worthy of attention; in these experiments, cats and monkeys were used in studying the influence exerted on the organism by large g-forces (up to 12 units). Only a few of the animals were anesthetized. The authors showed that under the influence of high g-forces the blood pressure, measured by means of a photoelectric manometer in the carotid artery, rapidly drops to zero, but increases in the femoral vein. The surface of the brain, which was photographed through a Forbes window, became pale at the time. Electrocardiographic studies revealed a disruption of the function of the myocardium of the right heart. Pathological anatomical autopsy of the animals revealed the presence of hemorrhages in the muscle layer of the right ventricle and also in the area of the roots of the lungs. With their data Jasper and Cipriani confirmed the findings of earlier authors in conjunction with the considerable significance of hemodynamics in the development of functional changes in the organism under the influence of g-forces.

Important data on the state of the circulation in the fundus of the eye under the influence of g-forces were obtained by Duane in 1954. Ophthalmoscopic observation of the fundus of the eye was performed when the subjects developed visual problems caused by the action of g-forces produced in a centrifuge. The author found that the action of the g-forces disrupted central vision; blood circulation in the arteries of the retina ceased. At the same time, however, the state of the venous blood circulation in this area showed no significant changes. On the basis of these data, the author concluded that the principal reason for the visual difficulties that arise under the influence of /57 g-forces is loss of blood from the vessels in the retina.

Other authors have mentioned the dependence of visual difficulties during exposure to g-forces on the state of the blood supply to the retina (Bergin, 1949; Fulton, 1948; Ruff, 1938; Stewart, 1945; V. V. Usachev, 1957).

The influence exerted on the human organism by g-forces during the use of anti-g devices was investigated roentgenologically by Rushmer (1947). As a result of the analysis of the data which he obtained, the author concluded that all of the phenomena that occur in the organism under the influence of g--forces are a function only of the increase in hydrostatic blood pressure in the heart-brain segment. This kind of simplified treatment of physiological mechanisms of the influence of g-forces on the organism, in our view, does not provide an exhaustive explanation of the facts which the author obtained.

It is clear from the above works of Soviet and foreign authors that the study of the influence of g-forces on the organism stressed the changes in the circulatory system. Many foreign authors have failed to pay sufficient attention, and have even completely ignored, the role and significance of nerve-reflex mechanisms in the compensation for changes that arise under the influence of g-forces both in the circulatory system and in the organism as a whole.

Influence of Transversely Directed G-Forces

In recent years, in conjunction with progress in rocket technology and rapid growth of cosmonautics, a great deal of attention has been paid to the study of transversely directed g-forces, inasmuch as the organism can withstand /58 their effects better.

In one of the first papers devoted to the study of the influence of g-forces under spaceflight conditions, Clark (1959) noted that a strictly transverse direction for the acceleration vector with respect to the lengthwise axis of the human body is not optimum for tolerance, but that an angle of 65° is better.

At the same time, one of the first Soviet studies devoted to evaluating the tolerance of man to transversely directed g-forces was published (V. I. Babushkin, E. V. Marukanyan, 1959). The authors noted that during exposure to these factors it was optimal to incline the back of the chair forward 20° (i.e., 70° with respect to the accleration vector). A. R. Kotovskaya et al. (1961), Mueller (1961) and A. S. Barer et al. (1965, 1967) found that the best angle for inclination of the back of the pilot's seat with respect to the acceleration vector was 78°.

Even in the very first experiments, the authors were turning their attention to the fact that one of the reasons for the limitation of tolerance to such g-forces is the disruption of the respiratory system. At the present time, as the result of studies that have been performed involving the use of various methodological approaches, it has been established that g-forces can deform the chest cavity and change the topography of its organs, disrupting the biomechanics of respiration, ventilatory function and gas exchange.

From the available sources, we know only a few works of the foreign and Soviet authors who have described the results of x-ray studies of the chest in man under the influence of transversely directed g-forces.

The first of these papers is that of Gauer (1938). In a number of experiments together with Ranke, he established that under exposure to /59 accelerations acting in the back-chest direction there is a compression of the chest cavity which increases parallel to the force acting on it. As a result, in the authors' opinion, the excursion of the chest is considerably impeded and the biomechanics of the respiratory act are disrupted.

Roentgenological studies during accelerations acting in the back-chest direction were conducted by Hershgold as well (1959, 1960). In these papers, the first attempt was made to give a description of the comparative characteristics of the roentgenoanatomical picture of the chest cavity in man during the experiment with varying degrees of tilting of the acceleration vector from the strictly transverse. The authors studied the influence of g-forces with magnitudes of 4 and 6 units, directed at an angle of 90° to the lengthwise axis of the human body; 6 and 12 units at an angle of 65° and values of 4 and 6 units acting in the side to side directions. It was shown that lateral action

of acceleration leads to characteristic changes in the topographic relationships of the organs in the chest.

In 1966, a paper by Sandler appeared in which the author describes the deformation of the chest cavity and the displacement of the heart during exposure to g-forces with magnitudes of 5 and 10 units, acting in the chest--back direction. Sandler performed experiments with a transverse direction for the acceleration vector with respect to the lengthwise axis of the human body (at an angle of 87°) using x-ray cinematographic methods. He essentially confirmed the data of other authors.

The work of A. S. Barer (1958), V. G. Petrukhin (1963), Yu. N. Korolev (1963) and others also showed that the action of considerable g-forces leads to pathological changes in the lungs.

According to the data of I. M. Khazen et al. (1963) the histostructural changes that occur following multiple exposures to g-forces bear a direct relationship to their frequency, force and number. /60

Studying the morphological changes in the animal organism under the influence of high transversely directed g-forces (8 units for 3 minutes and 12 units for 1 to 5 minutes), Yu. N. Korolev (1963), V. G. Petrukhin, M. M. Sokolova (1963) and others confirmed that the characteristic changes in the histostructure of the lungs during the early stages (1 hour, 24 hours) are plethora, edema of the pulmonary tissue, hemorrhages which indicate the disruption of hemodynamics in the lesser circulation under the influence of g-forces. At later stages (3 and 7 days) there are inflammatory phenomena in the pulmonary tissue and later still (15 and 60 days) focal sclerotization of the lung parenchyma develops.

V. G. Petrukhin (1966) found that frequently repeated exposure to g-forces in any direction, accompanied by even brief phenomena of "separation", may lead to cumulative damage to the myocardium, brain and heart. It may be assumed that subsequent exposures to a similar parameter of g-forces is capable of producing such slightly reversible changes in the organism as pneumosclerosis, emphysema, cardiosclerosis and hydrocephalus.

While the morphological disturbances, including the histomorphological ones, remain for varying lengths of time following exposure to g-forces, the functional changes as a rule disappear immediately afterwards. Roentgenological studies have shown that circulation in the lungs is restored rather quickly.

Interesting data were obtained by K. I. Murakhovskiy (1966, 1967), who used roentgenological studies to investigate the influence of prolonged longitudinal and transverse g-forces on the state of the organs in the chest cavity. The author found that g-forces acting for a long period of time produced deformation and specific changes in the topographical anatomical relationships of the organs in the chest, as well as changes in the amplitude of the respiratory movements of the ribs and diaphragm. /61

Hence, under the influence of g-forces on the organism, significant changes occur in various functional systems of the organism, especially the circulation.

In this connection, it is clearly necessary to perform additional studies of the influence exerted on the organism by long-acting g-forces. The study of the processes that are capable of revealing the protective-reflex mechanisms in the organism may lead to a successful solution of the problem of maintenance of working capacity by a pilot under conditions in which he is exposed to the action of this factor.

Method of Investigation Under the Influence of Prolonged G-Forces on the Organism

The research was performed on a centrifuge with a 3.66 m arm radius. At the opposite ends of the arms of the centrifuge, 2 suspended chairs were mounted, equipped with the necessary apparatus. The experiments developed centrifugal forces of a magnitude equal to those acting in the head-feet direction.

The time required for the g-forces to rise to the second value was 10 to 15 seconds, and the elapsed time before the centrifuge stopped following rotation was 10 seconds. An x-ray apparatus was mounted behind the back of the suspended chair on the centrifuge on special bearings; the x-ray apparatus was in the form of a block transformer composed of the x-ray tube and the high voltage transformer. /62

The instruments (x-ray cassette, small portable apparatus) for obtaining the x-ray pictures were mounted on the front arch of the chair. The apparatus (oscillograph and other monitoring devices) was mounted on a special stand at the axis of the centrifuge.

We carried out two stages of the work in performing the x-ray investigations. In the first stage the experiments were conducted on animals (dogs) and in the second research was performed with the participation of human beings.

Characteristics of the Method of Investigation of Animals

The experiments were performed on dogs weighing 6 to 10 kg. The method of angiocardiography was used to study the nature of the blood flow in the lesser circulation and in the chambers of the heart in unanesthetized animals. X-ray photographs of the organs in the chests of the experimental animals were taken under original conditions, at the time of exposure to a g-force directed from the head to the pelvis and 1-10 minutes following the end of experiments. X-ray investigation was conducted at g-forces of 3, 6 and 9 units, using only series roentgenography.

When taking a series of photographs, the camera was mounted on the front arch of the centrifuge chair (Figure 9). Using this device made it possible to obtain x-rays with a time interval of 1 second between them during the necessary time interval.

In studying the characteristics of blood flow in the lesser circulation and in the chambers of the heart, their contrasting was carried out by means of administration of "torotrast" into the superior vena cava of the animal.

We introduced 10 ml of torotrast, heated to body temperature, into the superior vena cava using a rubber catheter. Under local anesthetic (2% solution of novocain) the skin of the animal's neck was opened and the vein separated out; the catheter was then inserted into the latter so that its /64
end, with a metal olive, reached the mouth of the superior vena cava. Administration of the contrasting substance was performed automatically one second after the beginning of continuous series x-raying by means of the special device and lasted 1 second. The animal was immobilized on a stand by means of special belts so that the breathing was not impeded in any way.

When the organism was exposed to g-forces, the animals developed significant changes in the blood circulation in the chambers of the heart and in various portions of the vascular tree of the lesser circulation. They consisted in the following: the rate of movement of the contrasting substance increased, while the volume of the contrasting substance passing through sharply declined. A relationship was also established between the rate of passage of the contrasting substance and the magnitude of the g-force produced. The time it required to pass through the lesser circulation, as a rule, continually decreased with increasing level of g-forces, while the duration of its stay in the chambers of the heart, on the other hand, increased.

It was found that while the first portion of contrasting substance appeared in the right ventricle at the 4th second prior to administration of g-forces to the organism and in the left ventricle at the 4th second, following exposure to g-forces of 3 units, these values change to the first and second seconds, respectively, and at 6 and 9 units to 1 second.

Under the original conditions, the contrasting substance could be found in the right ventricle in 4 pictures, i.e., in 4 seconds, and under the influence of g-forces of 3, 6 and 9 units after 5, 6 and 7 seconds, respectively. In all other parts of the heart the delay time under the influence of g-forces was the same as in the right ventricle. The delay in the movement of the /65
contrasting substance at the time of exposure to the g-forces was noted in the vessels of the caudal portions of the lungs as well.

As a result of the roentgenological studies that were performed, it was established that the dimensions of the contrast-filled chambers of the heart and the large vessels decrease under the influence of g-forces.

In Figures 10 and 11 one can see the state of the contrast-filled chambers of the heart and large vessels under original conditions and under the influence of g-forces with a magnitude of 9 units on the organism. Similar changes in the chambers of the heart were observed in all the other experiments.

The results of the linear and planimetric measurements of the heart shadow and large vessels in the x-rays which were performed revealed that under the

influence of g-forces there is a decrease in the size of the chambers of the heart and of the large vessels as well. Thus, for example, under the influence of g-forces of 3, 6 and 9 units, the area of the projection of the right ventricle decreased to 4, 3 and 2 cm^2 respectively and the left ventricle to 8, 6 and 5 cm^2. Prior to exposure to g-forces the area of the right ventricle was 5 cm^2 and that of the left was 9 cm^2; the width of the superior vena cava decreased to 0.8-0.6 and 0.3 cm (prior to exposure it was 0.9 cm), while the arch of the aorta changed to 1.5-1.5 and 1.4 cm (prior to exposure it was 1.6 cm).

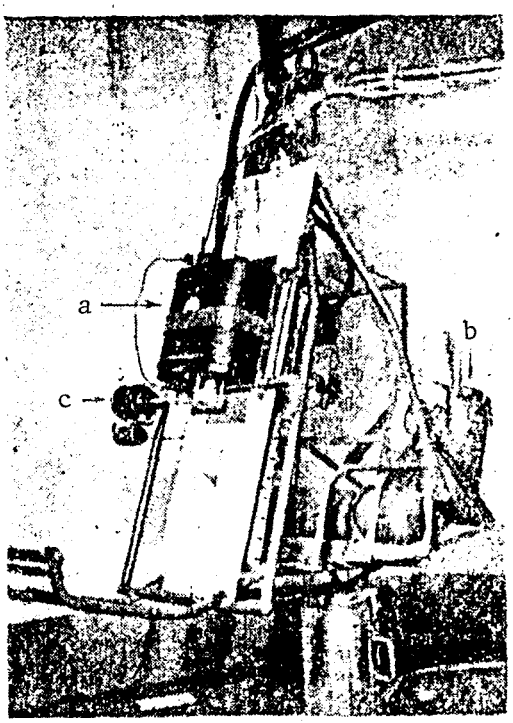

Figure 9. Device for Series X-raying in Animal Experiments in a Centrifuge: (a), removable device for series x-rays; (b) block transformer of x--ray apparatus; (c) electric motor.

This material indicates the direct relationship that exists between the magnitude of the acting g-force and the degree of reduction of the contrast image of the chambers of the heart and the large vessels. In addition, these data show that contrast images of various parts of the heart under identical g-force conditions are manifested in varying degrees. In all of the experiments there was a more marked reduction in the size of the right ventricle in comparison to the left. In the available x-rays, as in /68 those x-rays that were taken in our other studies, there was no case of complete absence of contrasting substance in the chambers of the heart and the aorta, even under the influence of g-forces with a magnitude of 6 and 9 units.

Our data do not agree with the results of work performed by certain foreign authors, which indicated that there is an "emptying" of the heart of blood under the influence of a g-force of 4.4 units.

As we have indicated, this contradiction probably is explained by the fact that in contrast to the work of foreign authors, our research was performed on unanesthetized animals and in the absence of strong restraint.

The method of angiocardiography made it possible not only to determine the relative changes in the linear velocity of blood flow in the lesser circulation but also to study the nature and degree of deformation of various parts of the heart and large vessels.

Figure 10. X-Ray of the Organs of the Chest Cavity of the Dog Bobit, 6 Seconds After the Beginning of Administration of "Toratrast" Under Initial Conditions: a, outline of the heart shadow; b, outline of the diaphragm shadow. Administration of contrasting substance revealed the following: 1, left auricle; 2, left ventricle; 3, ascending branch of the aorta; 4, arch of the aorta; 5, descending branch of the aorta.

The studies that have been performed have shown that under the influence of g-forces there is a deformation of the chambers of the heart, primarily its right portions, as well as the large vessels in the chest cavity. It is necessary to suggest that the displacement and deformation of the heart and large vessels which are observed under the influence of g-forces must naturally have a negative effect on their normal functioning.

The results of x-ray studies on animals confirm the views held earlier that during action on the organism of centrifugal force directed in the cranio-caudal direction there is a decrease in the heart size and a decrease in the intensity of its shadow. These phenomena indicate a decrease in the filling of the heart with blood. Displacement and deformation of the internal organs, /69 which are observed during the exposure of the organism to g-forces, are a function of the magnitude and duration of the g-forces produced.

Figure 11. X-Ray of the Organs of the Chest of the Same Dog 4 Seconds After the Start of Administration of Thoratrast During Exposure to G-forces of 9 Units. 1, right ventricle; 2, pulmonary vessels; 3, left auricle; 4, left ventricle; 5, ascending branch of aorta; 6, arch of the aorta; 7, descending branch of the aorta. /67

Hence, under the influence of g-forces of 9 units, unanesthetized animals suffer a decrease in the filling of the heart with blood. The increase in the rate of passage of the contrasting substance through the lesser circulation clearly is the result of an increase in the compensatory reactions that are directed at accommodation of the organism to the action of the g-forces.

Characteristics of the Method of Investigation with Human Subjects

Twenty men aged 20 to 32 were studied, recommended by the medical commission as being suitable for participation in experiments on the centrifuge. Three series of tests were performed. In the first, the influence of g-forces directed in the head-seat direction was studied without using any g-suits. In the second series, the influence of the same factor was studied using two types of g-suits: PPK-1 and PPK-2. The PPK-1 has 5 chambers: one of them exerts

pressure on the stomach, two on the pelvis, and two on the shins. In this suit some parts of the body (the buttock region and the coxofemoral and knee joints) were unprotected. The PPK-2 is the lower part of the pressurized suit and has one ventral sleeve. It covers all parts of the body below the rib cage and exerts a uniform pressure on the body by means of blowers. In the third series the condition of the organs in the chest cavity was investigated 10 to 20 minutes after the termination of exposure of the organism to g-forces in the chest-back direction.

When the seat of the movable chair on the centrifuge was in a position such that the angle of the back was 16 to 20°, the subject in each of the experiments in the studies in the first series was successively subjected to /70
the action of g-forces measuring 2, 3, 4, 5 and 6 units, and in some cases 7 and 7.5 units; in the second series, using the PPK; they were subjected to 5-9 units (Table 5). The duration of exposure to the g-forces was 20 seconds.

TABLE 5. DISTRIBUTION OF STUDIES BY MAGNITUDE OF G-FORCES

Series of studies	No. of studies	Magnitude of G-forces, Units									
		2	3	4	5	6	6.5	7	7.5	8	9
First	140	12	3	19	62	25	2	15	2	-	-
Second	156	-	-	-	64	31	-	38	-	20	3
Third	6	-	-	-	1	1	-	3	-	1	-

Anterior direct roentgenography of the organs of the chest and the upper part of the abdominal cavity was performed prior to the test, during the 20th second of exposure to the g-forces, and after 2 minutes or more had elapsed following the end of the experiment. In individual experiments, when the PPK was used, roentgenography was performed also at the second minute of exposure of the organism to the g-forces.

In the third series the subjects were subjected to the action of g-forces with a magnitude of 5-8 units lasting up to 5 minutes without using the PPK.

In some of the studies, preliminary contrasting of the gastrointestinal /71
tract was performed. For this purpose, the subject, 20 to 50 minutes prior to the start of the test, was given barium sulfate in an aqueous suspension (100 g of barium per 200 g of water). The pictures were taken at the time of termination of maximum inspiration. When the PPK was used and the organism was subjected to g-forces, x-rays were taken under original conditions and during rotation both at the time of termination of maximum inspiration and expiration for the purpose of obtaining data on the nature of the influence of devices to protect against the action of g-forces on the volume of the respiratory movements. During all of the investigations, we conducted systematic clinical observations on the state of health and roentgenological examination of the

bone system and organs of the chest. Particular attention was given to the condition of the heart and large vessels since, on the basis of the data in the literature and the results of our studies, the greatest disturbances resulting from the action of g-forces arise primarily in the circulatory system.

Changes in the Organs of the Chest and Abdominal Cavities Under the Influence of G-forces Directed from the Head to the Feet Without Using a G-suit. The study of x-rays taken at the time the organism was exposed to g-forces showed that under these conditions the configuration and location of the heart, aorta, diaphragm, stomach and intestine were considerably altered. The degree of this change was a function of the magnitude of the g-forces to which they were exposed (Figures 12-14).

From what is shown on Figures 12 and 14 it is clear that the dimensions of the heart shadow in both the longitudinal and transverse directions as well as its area experienced a decrease. The transverse dimension of the shadow of the /74
arch of the aorta also decreased, although its length, on the other hand, increased slightly.

Figure 12. X-Ray of the Organs in the Chest Cavity of Subject K Prior to Exposure to G-forces.

Figure 13. X-Ray of the Organs in /72,73 the Chest Cavity of the Same Subject, 20 Seconds Into Exposure to a G-force of 2 Units.

The results of linear and planimetric measurements of the principal parameters of the projection of the heart and vascular bundle in the x-rays of subject K are shown in Table 6.

Figure 14. X-Ray of the Organs in the Chest of the Same Subject, at the 20th Second of Exposure to G-force of 5 Units.

As we can see from Table 6, as the magnitude of the g-force increases, the dimensions of the heart and the width of the arch of the aorta decrease, while the length of the arch of the aorta, on the other hand, increases.

The degree of displacement of the heart and an increase in the length of the arch of the aorta under the influence of g-forces acting in the head-feet direction is probably dependent to a considerable extent on the degree of displacement of the organs in the abdominal cavity and the diaphragm. However, the decrease in heart size and diameter of the arch of the aorta observed under these conditions indicate a decrease in the filling of these organs with blood.

X-rays have also made it possible to trace developing changes in the position of the cupulas of the diaphragm. Under the influence of g-forces the displacement of the cupolas of the diaphragm as a rule was irregular. Thus, while the influence of g-forces cause the right cupola to be displaced to almost the same degree as the heart, the left cupola, when exposed to high g-forces, was elevated. The latter was observed when the organism was exposed to g-forces measuring 7-7.5 units. /76

TABLE 6. CHANGE IN SIZE OF HEART AND LARGE VESSELS AS A FUNCTION OF MAGNITUDE OF G-FORCES /75

Magnitude of g-force, units	Heart			Vascular bundle	
	Diameter cm	Length cm	Area cm^2	Width cm	Length cm
1	14.7	16.4	150	7.7	10.8
2	14.1	16.4	140	7.6	11.1
	-4.0	0	-6.7	-1.3	+2.8
4	13.9	16.6	137	7.3	12.2
	-5.4	+1.2	-8.7	-5.2	+12.9
5	11.3	13.7	103	6.9	13.6
	-23.1	-16.5	-31.3	-10.4	+25.9
7	11.3	12.7	103	7.1	14.3
	-23.1	-22.6	-31.3	-7.8	+32.4

Note: The minus sign indicates a decrease and the plus sign indicates an increase in the dimensions (in %).

As we have already pointed out, the elevation of the left cupola of the diaphragm under the influence of g-forces probably occurs due to an increase in the intraperitoneal pressure, which arises as the result of displacement of internal organs and the considerable stress on the muscles of the abdominal press.

The above mentioned details of the x-ray picture of the organs in the chest cavity in man during exposure to g-forces were observed in all of the tests.

As a result of a comparison of the x-rays that were obtained for different subjects exposed to the same g-forces, it was found that there is a certain relationship between the degree of the occurring changes in the heart size and the individual characteristics of the organism. When the value of the acting g-force does not exceed 4 units, the decrease in the size of the heart shadow occurs more markedly in individuals with a low resistance to acceleration.

Individual differences were also observed in a comparison of the degree of decrease in the intensity of the heart shadow which was observed in all of the subjects. However, the occurrence of this phenomenon in individuals with low resistance to the effect of g-forces may be viewed as taking place at 4 units, while in the case of individuals with considerable resistance it began to appear only at 5 units.

It is important to mention that in those cases when the magnitude of the g-forces was low (up to 4 units) individual differences in the changes in the internal organs were clearly pronounced. However, if the g-force exceeded 5 units, the differences were smoothed out to a degree that increased with the magnitude.

It is important to note that during the exposure to the action of g-forces /77
there are characteristic changes in the bioelectrical activity of the heart as evidenced by the electrocardiogram: development of sinusoidal tachycardia and a decrease in the R and T peaks (B. V. Malkin, 1957).

The x-rays of the subjects showed a decrease in the width of the shadow of the roots of the lungs during exposure to g-forces. In the upper areas of the pulmonary picture, an increase in the magnitude of the g-force led to a fading that was so serious that it was sometimes difficult to determine whether the image was present, while in the lower sections, on the other hand, there was a marked increase.

The fading or darkening of the pulmonary picture may occur as a result of a different degree of blood supply to the pulmonary vessels, as well as a change in the amount of air in the pulmonary alveoli. It is quite clear that the action of g-forces on the organism leads to a non-uniform filling of the upper and lower parts of the lungs with blood, i.e., loss of blood from the vessels in the upper parts of the lungs and, on the other hand, overfilling of the vessels in the lower parts.

In 5 subjects, together with an x-ray examination of the organs of the chest cavity (heart, major vessels, lungs, diaphragm), during exposure to g-forces with a magnitude of 2-7 units, the state of the stomach and the proximal portions of the small intestine were also determined. These studies were conducted following preliminary contrasting of these organs. X-rays were made 20 seconds following the start of exposure of the organism to g-forces. An analysis of the x-rays revealed that under the influence of the g-forces there were instances of deformation and displacement of these organs. Under these conditions, the stomach showed marked lengthening, while the visible parts of the small intestine were displaced in the caudal direction. The degree of these /78
changes bore a certain relationship to the magnitude of the g-forces produced: as the latter increased, the phenomena of deformation and displacement increased as a rule.

Thus, under the influence of g-forces acting on the organism there is a decrease in the blood supply to the heart and the large vessels, displacement and deformation of the internal organs and a change in the pulmonary picture.

In x-ray studies that were conducted 2 minutes following cessation of exposure of the organism to g-forces of 5 units or more, the picture of the pulmonary tree in the subjects was the same as under the original conditions, i.e., there were no significant differences. The magnitude of the area of the heart shadow in those individuals that exhibited a low resistance to g-forces was slightly higher than under the original conditions, while there was no change in the more resistant individuals. Following exposure of the individuals to g-forces with a magnitude of 2-4 units, none of the subjects showed any kind of significant changes in heart size. In those x-rays that were taken 10 minutes or more after exposure to the g-forces, the size of the heart shadow in all of the subjects was the same as under original conditions.

These data indicate that the changes in the cardiovascular system and in the lungs which are observed under the influence of g-forces have a functional and reversible nature.

This is also indicated by clinical x-ray observations that we conducted on subjects who had been subjected to systematic (with large interruptions of 5 to 7 days or more) and multiple (from 6 to 300 times) exposure to g-forces from 2 to 9 units lasting up to 20 seconds for a period of 1 to 3 years. The skeletal system and organs of the chest of these subjects showed no deviation from the norm.

State of the Organs of the Chest and Abdominal Cavity Under Conditions of /79
Exposure to G-Forces Directed from the Head to the Feet, with Use of a G-Suit.

As we have already pointed out, the greatest changes under the influence of g-forces were noted in the circulatory system. It was also established that when the g-suit was used, due to the increase in the volume of circulating blood in the upper half of the body, the flow of blood to the heart increased. This is why it is very important to study by means of the method of x-rays the characteristics of the changes in the internal organs in subjects under conditions of exposure of the organism to g-forces while wearing a g-suit.

Under the conditions that existed when counterpressure was produced, even under exposure to high g-forces, the subjects showed no such marked changes or deformations in the internal organs as occurred in tests without the g-suit. Thus, if the g-suit was not worn by the individuals during the exposure of his organism to the g-forces, as we have already pointed out, the heart assumed a "drop shape" and assumed a strictly median position, with a decrease in its longitudinal and transverse dimensions, and the size of the heart shadow also decreased. However, if a g-suit was worn under these conditions, changes of this kind were seen only to an insignificant degree and were not observed at all in certain cases.

For the sake of illustration, let us examine the x-rays of subject V (Figures 15-17).

It is clear from Figures 15-17 that when the g-suit is worn during the exposure to g-forces, the diaphragm (and consequently the heart) retains a higher position, and the area of the heart shadow and the dimensions of the large vessels show essentially no change.

Figure 15. X-Ray of the Organs of the Chest in Subject V Prior to Exposure to G-forces.

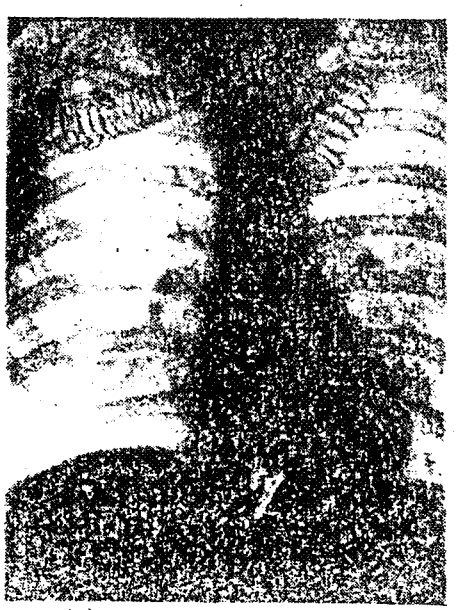

Figure 16. X-Ray of the Organs of the Chest of the Same Subject, 20 Seconds After the Beginning of Exposure to a G-force of 5 Units Without Wearing a G-suit.

As a result of a comparative study of the influence exerted on the human organism by g-forces while wearing various g-suits it was established that the changes in shape and position of the internal organs of the subjects were linked primarily to the characteristics of the design of the particular g-suit that was used. Thus, when the PPK-1 g-suit was used, the hearts of all of the subjects exposed to g-forces were displaced in the cranial direction and assumed

a more horizontal position in comparison with the original picture. The reason for this was the sharp rise of the diaphragm as a result of compression of the anterior abdominal wall by the sleeve of the g-suit. The longitudinal and /83
transverse dimensions of the heart shadow as well as its area decreased slightly. There was also a slight decrease in the length and increase in the width of the shadow of the vascular bundle.

When the PPK-2 g-suit was used, the above mentioned changes were pronounced to a lesser degree than when the PPK-1 was worn. The transverse dimension, length and area of the heart shadow as well as the width and length of the shadow of the vascular bundle remained unchanged in the majority of subjects in comparison with the original picture and the position of the heart also remained unchanged. It was only when high g-forces were imposed on the organism that a slight displacement of the heart in the caudal direction was observed.

Figure 17. X-Ray of the Organs of the Chest of the Same Subject, 20 Seconds Into the Exposure to G-forces of 5 Units Using the PPK-2 G-suit.

A graphic representation of the organs in the chest of subject V during exposure to g-forces of 5 units while wearing the PPK-1 and PPK-2 is shown in Figure 18.

Figure 18 clearly shows the changes in the shape and position of the heart large vessels and diaphragm.

The data from linear and planimetric measurements of the principal parameters are listed in Table 7. In the case when the PPK-2 was worn the sizes of the heart and vascular bundle increased noticeably in comparison with the original situation.

An analysis of the x-rays that were /82
taken also show that under conditions of exposure to g-forces (up to 9 units) the degree of intensity of the heart shadow does not change significantly if anti-g-force measures are taken. This all indicates an absence of noticeable changes in the filling of the heart with blood when a g-suit is worn.

The x-ray picture of the lungs also changes less when a g-suit was worn during exposure to g-forces. There was only a slight decrease in the clarity /84
of the lung pattern in the upper areas of the lungs and there was no change whatsoever in the lower parts of the lung picture; it was only in individual cases that there was an increase in intensity.

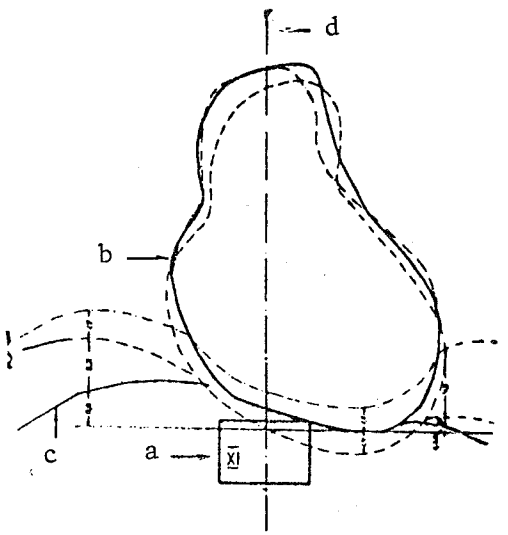

Figure 18. Graphic Representation of the Changes in the Organs of the Chest of Subject V During Exposure to G-forces of 5 Units While Wearing a G-suit (Superimposition Was Performed Along the Projection of the 11th Thoracic Vertebra). 1, Original position; 2, 5 units, PPK-2; 3, 5 units, PPK-1; a, corpus of the 11th thoracic vertebra; b, outline of the right portion of the heart; c, outline of the right cupola of the diaphragm; d, midline.

We fail to find a single roentgenological article devoted to the study of the characteristics of the change in mobility of the diaphragm and the ribs during exposure of the organism to g-forces under conditions when counterpressure was applied. In addition, the study of this problem is not only of theoretical but great practical significance for working out the design of various types of g-suits, inasmuch as changes in the mobility of the diaphragm and ribs have a significant influence on the function of the external respiration.

Under the influence of g-forces while wearing both the PPK-1 and PPK-2, the changes in the pulmonary picture /86 were accompanied by a disruption of the mobility of the diaphragm and ribs. A considerable decrease in the amplitude of the movements of the diaphragm was found and (on the other hand) there was a slight increase in the amplitude of the respiratory movements of the ribs, especially when the PPK-1 was worn.

The data obtained indicates that during exposure to g-forces while wearing a g-suit there is a significant decrease in ventilation of the lower areas of the lungs. In addition there is a slight increase in the volume of the thoracic respiration. The latter is probably a compensatory-accommodative reaction of the organism in response to the circulatory disturbances developing in the lungs.

As the results of the investigation of the stomach and small intestine following intake of barium sulfate on the action of g-forces while applying counterpressure to the body, it was found that there was an increase in their transverse dimensions. These changes obviously arose because the abdominal cuff of the PPK exerted a mechanical pressure on the anterior abdominal wall. No displacement of the stomach and small intestine in the caudal direction was observed under these conditions.

Data from an x-ray study of the heart, lungs, diaphragm and large vessels as well as the organs of the chest under conditions of exposure of the organism to g-forces confirmed the statements of a number of authors (D. Ye. Rozenblyum,

1955; P. K. Isakov, 1956, and others) that when g-suits are worn more favorable conditions are created for the functional activity of the internal organs, especially in the case of the circulatory system.

TABLE 7. DIMENSIONS OF HEART AND LARGE VESSELS UNDER INITIAL CONDITIONS AND 20 SECONDS INTO THE EXPOSURE TO G-FORCES USING VARIOUS TYPES OF G-SUITS. /85

Magnitude of g-forces	Heart			Vascular Bundle	
	cross-section, cm	length, cm	area, cm^2	width, cm	length, cm
1 unit without g-suit	18.7	18.0	192	8.1	8.9
5 units without g-suits	15.1	15.5	155	6.7	13.5
	-19.3	-13.9	-19.3	-17.3	+51.7
5 units with g-suit PPK-1	16.5	17.5	178	7.0	8.1
	-11.8	-2.8	-7.3	-13.6	-5.6
5 units with g-suits PPK-2	17.3	18.7	205	8.1	8.1
	-7.5	+3.9	+6.8	0	-9.0

Note: Minus sign indicates a decrease and the plus sign indicates an increase in the dimensions (in %).

We found that when the PPK-2 g-suit was used the disturbances in the circulatory system were manifested to a lesser degree than when the PPK-1 was worn. These data confirm the results of physiological studies conducted by V. I. Babushkin et al. (1959) indicating a high degree of effectiveness of the PPK-2 in comparison to the PPK-1. /87

The higher degree of efficiency of the PPK-2 was achieved as a result of the provision of uniform pressure on the lower half of the body. The data that had been accumulated indicate the necessity for further work on the part of designers in collaboration with aviation physicians with the goal of finding and developing still more efficient means of protecting the organism against the action of g-forces.

Hence, the results obtained in the investigational data indicate that under the influence of g-forces a decrease develops in the heart size, there is a decrease in the intensity of the shadow of the latter, alterations in the lung picture, etc. These changes depend both on the magnitude and duration of the acting g-force.

The data from x-ray studies indicate significant disturbances in the circulatory system related to a decrease in the flow of blood to the heart.

In turn, the disturbances of the function of the cardiovascular system that are observed during exposure to g-forces have a negative effect on the normal blood supply to vitally important organs, primarily the central nervous system, leading to a decrease in the working capacity of the individual.

Afferent impulses arising during the displacement and a deformation of tissues and organs probably also have a certain negative influence on the functional state of their central nervous system.

Disturbance of vision in various individuals arose at different g-force levels, which probably is associated with the characteristics of the functional state of the cardiovascular system, which determine the individual resistance /88
of the subjects to the action of the factor under study.

The nature of the roentgenological changes that were detected in the shadow of the heart and aorta still do not provide a complete basis for evaluating the state of the circulatory system as a whole, especially the nature of the blood supply to the brain.

It must be assumed that in addition to the profound changes that occur in hemodynamics, the displacement and deformation of the internal organs which occur under exposure to g-forces can also cause disturbances in their normal functions.

Under exposure to g-forces with a magnitude of 5-9 units under conditions when a g-suit is worn, the dimensions of the heart shadow and its intensity do not change significantly. There are no significant displacements or deformations of the internal organs.

Clinical x-ray observations have shown that multiple and systematic (from 1 to 3 years) exposure of the human organism to g-forces of 2 to 9 units does not produce any visible pathological changes involving the bone system and the organs of the chest.

Our data and the data in the literature indicate a necessity for developing still more efficient anti-g-force measures to create uniform pressure on the body and to prevent the development of severe disturbances of the functional systems of the organism and especially the circulatory system.

Changes in the Organs of the Human Chest Under the Influence of G-Forces Directed from the Chest to the Back. Under the influence of large and small transverse g-forces 95-8 units, acting at an angle of 78° to the acceleration vector, lasting up to 8 minutes without the g-suit), the subject showed insignificant, transient, non-uniform increases in the lung picture).

/89

In addition, there may be significant disturbances to the circulatory system, especially the vessels of the lesser circulation. Redistribution of the blood in the lesser circulation occurred, with predominant deposition of the blood in the posterior areas of the lungs. This led to stagnation phenomena with subsequent development of edema of the lungs and atelectases.

As a result of the study of remote results obtained during the dynamic clinical-x-ray investigation of the organs of the chest in subjects who had been subjected to the systematic action of large and prolonged transverse g-forces, it was found that the organs of the chest manifested no significant morphological changes.

Influence of Angular Accelerations

Flight aboard spacecraft in orbit and the return to Earth when the stabilization system of the craft is disturbed, ejection of pilots (cosmonauts) from the cabin of the craft, as well as prolonged free fall of the body when making a parachute jump, are accompanied as a rule by rotation of the individual around axes that run in various directions relative to the body. According to preliminary determination, the rate of rotation of the individual then can reach extremely high values, posing a serious threat to life. In this connection, much attention is being given at this time to the study of this problem and the development of preventive measures.

At the present time, there has as yet been insufficient experimental investigation of the influence of the forces that occur during rotation of a seat with a pilot in it in the air. The first preliminary studies that were /90
conducted in Germany during World War II showed that an individual can withstand without any harmful consequences a period of 1 minute of rotation at a rate of 90 rpm provided that the axis of rotation of the body passes through the body body's center of gravity.

Lombard, Ames, Roth and Rosenfeld (1951) subjected individuals to rotation at the rate of 40 rpm and observed no vertigo in them. They found that those forms of rotation in which the axis is located at the level of the heart are easiest to withstand.

Sperry (1957), in summarizing the results of flight and laboratory tests, noted that one of the symptoms of an unfavorable outcome of ejection during the flight of modern aircraft is the rotation of the ejected individual at a high rate of speed around his center of gravity, primarily during free fall. Although such rotation usually lasts several seconds, it can pose serious danger to life.

Other authors (Taylor, Johnson, Sellers, 1960, etc.), studying the changes in the cardiovascular system during the rotation of an individual in a chair, noted the development of bradycardia, cardiac blockage, etc. These changes were attributed by the authors to reflex reactions that occur in the area of the carotid sinus.

S. S. Makaryan et al. (1962, 1964) found that rotation for 20 minutes around the lengthwise axis of the body at a rate of 1.75 revolutions per second constitutes the limit of tolerance. A marked acceleration of the pulse, increases in systolic index and minimum arterial pressure, indicating pronounced functional disturbances in the activity of the cardiovascular system, developed during rotation, beginning at a speed of 1.5 revolutions per second. In /91
individuals with lower vestibular sensitivity these changes were observed during rotation at a speed of 2 revolutions per second. All of this was the result of exposure to the effects of angular accelerations.

Hence, determination of the permissible speeds of rotation of an individual around axes passing through the body is a timely problem for modern aviation and cosmonautics. Thus far, foreign authors have studied rotation for relatively short periods of time — several seconds or so, and only in one plane. Under conditions of development of rocket technology and conquest of space, new requirements are arising with respect to this problem.

Characteristics of the Method of Investigation During Exposure to the Action of Angular Accelerations

Eleven healthy young men were studied to determine the nature of the disturbances to the functional state of the cardiovascular system and respiration. The effect of angular accelerations was studied at various rates of rotation and angles of inclination of the trunk. The rate of rotation was between 0.5 and 2 revolutions per second, creating angular accelerations from 15 to 120°/second^2. The time of rotation in each test was 1 to 5 minutes, with an interval of 10 to 25 minutes between rotations. The subjects were rotated around an axis passing through their pelvic area, with their trunks inclined 0, 20, 30 and 65° from the vertical (Figure 19).

Several subjects underwent these studies 2 to 3 times. A total of 18 tests were performed. Before and after exposure to the accelerations, the electrocardiogram was recorded and x-rays were taken of the chest; roentgenokymography of the heart and large vessels was also performed. X-rays of the organs of the chest were taken in the anterior direct projection during retention of the breath at the level of maximum inspiration, and the roentgeno- /92
kymography of the heart and large vessels was recorded at the quiet inspiration level. The state of the organs in the chest as indicated by the x-rays was studied visually and by measuring their principal parameters.

Rotation in the vertical position (sitting). Multiple prolonged angular accelerations cause certain changes in the organs of the chest. In the majority of cases, they are shown in x-rays as an increased transparency of the lower portions of the lungs and an increase in the density of the shadow of the radices and areas near the radices. These changes were of /93
a functionable reversible nature.

Rotation with the trunk and head inclined forward at an angle of 20°. Prolonged angular accelerations cause certain changes that are linked primarily to a disturbance of the lesser circulatory system. In the upper and median

portions of the lungs, there was a slight increase in the lung picture, expansion of the shadow of the radices, this was caused by an increase in the filling of the vessels with blood. These changes in the lungs were reversible.

The roentgenokymograms of the subjects 20 minutes after the end of the tests showed a sharp increase in the heart size. The entire right outline of the heart shadow, as well as the outline of the left ventricle in the vicinity of its apex, from a distance of 6 cm showed no roentgenokymographic peaks. In the vicinity of the base of the left ventricle the amplitude of the peaks was less than under the initial conditions. These changes indicate a significant disturbance to the contractile function of the heart muscle.

The arch of the pulmonary artery was also dilated. Its outlines showed a marked decrease in the amplitude of the roentgenokymographic peaks. Along the arch of the aorta the shape of the peaks had no significant changes, but their amplitude was slightly decreased in comparison with the original.

In a roentgenokymograph that was recorded on the second day following termination of the test, the dimensions of the heart remained slightly increased. Everywhere along the outline one could see roentgenokymographic peaks of normal shape, but their amplitude was decreased and the large vessels remained unchanged.

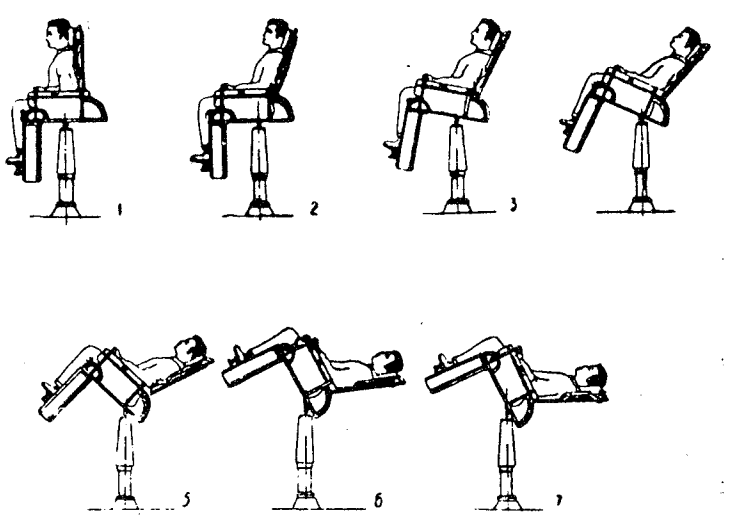

Figure 19. Principal Positions of the Chair. Individual in Chair: 1, at 0°; 2, at 20°; 3, 30°; 4, 45°; 5, 65°; 6, 80°; 7, 90°.

For the sake of illustrating the changes described above, let us examine /94 Figures 20-22.

The indices of the linear and planometric measurements of the heart and vessels on roentgenokymograms are shown in Table 8.

TABLE 8. DIMENSIONS OF THE HEART AND LARGE VESSELS IN ROENTGENOKYMOGRAMS OF SUBJECT M

Time of roentgeno-kymography	Heart			Vascular bundle	
	Cross-section cm	Length cm	Area cm^2	Width cm	Length cm
Prior to the test	15.2	16.7	163.0	5.9	8.6
After the test:					
20 minutes	16.1	17.4	174.0	6.3	9.0
	+5.9	+4.2	+6.7	+6.8	+4.6
24 hours	15.6	17.1	168.0	5.9	8.8
	+2.6	+2.1	+3.1	0	+2.3
10 days	15.3	16.8	161.0	6.0	8.8
	+0.7	+0.6	+0.6	+1.7	+2.3

Note: Plus sign indicates an increase in dimensions (%).

Rotation with the trunk and head inclined backward at angles of 30 and 65%. The organs of the chest in these subjects showed slight reversible functional changes: a slight enlargement of the lung picture and an increase in the size of the heart shadow without any disturbance of the contractile function of the heart muscle.

In the x-rays of the organs of the chest in the case of these subjects, 6-7 days after the end of the test, there were no deviations from the norm.

Thus under the influence of multiple angular accelerations, a number of reversible functional changes occurred, primarily involving the lungs and heart. Frequently the changes in the size of the heart shadow were accompanied by a disruption of the contractile function of the heart muscle: a decrease in the amplitude of the roentgenokymographic peaks in the vicinity of the apex of the left ventricle with a rounding of the apices of these peaks or an absence of these peaks in certain areas of the heart shadow.

It should be pointed out that in a general clinical examination these subjects fail to show any significant changes affecting the heart.

As the results of our studies indicated certain individuals with low resistance to the action of angular accelerations revealed significant changes in the contractile function of the heart following the completion of rotation, with these changes being evidenced by a lack of pulsation in its boundary area.

Figure 20. Roentgenokymogram of the Heart and Large Vessels of Subject M Prior to the Tests.

Figure 21. Roentgenokymogram of the Heart and Large Vessels of the Same Subject 20 Minutes After The Test. /95,96

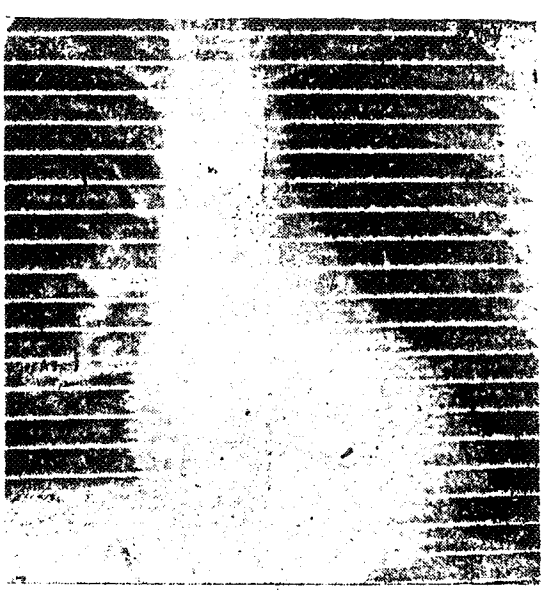

Figure 22. Roentgenokymogram of the Heart and Large Vessels of the Same Subject on the 2nd Day Following the Test.

The development of a "blank zone" in the outline of the heart shadow following the experiments in the rotating chair, in our opinion, was linked to reflex vasomotor disturbance of the coronary circulation, resulting in the development of a temporary disturbance of the blood supply to the heart muscle. An analysis of the data obtained indicates that this reflex reaction is associated with an extreme stimulation of the vestibular apparatus under the influence of multiple angular accelerations.

A significant role of disturbances to nervous regulation of coronary vessels in the pathogenesis of damage to the myocardium is indicated /97 in other works as well (A. V.

Smol'yannikov, A. K. Apatenko, 1954; S. S. Vayl', 1960; A. V. Smol'yannikov, 1962, etc.).

Clinical-x-ray observations (Yu. I. Arkusskiy, 1948, etc.) established that, when a muscle is subjected to stress, its blood supply becomes insufficient and various changes occur as a result. For this reason, changes in the myocardium are observed in those areas which perform the greatest work. This is why the "blank zone" is most frequently observed in the vicinity of the apex of the left ventricle.

The results of the experimental data obtained make it possible to draw the following conclusions:

— Following exposure of the organism to multiple angular acclerations, as a rule, there is an increase in the dimensions and intensity of the heart shadow, indicating an increase in its filling with blood;

— changes in the organs of the chest following exposure of the organism to multiple angular acclerations were more pronounced than in the case of single exposures. This evidently indicates a lack of training for this type of influence; /99

— the changes observed in the organs of the chests of the subjects after the termination of the experiment were of a functional reversible nature.

CHAPTER III. INFLUENCE OF EXPLOSIVE DECOMPRESSION ON THE ORGANISM /103

During high altitude and spaceflights it is necessary to take into account still another very important factor which arises when the pressurization of the cabin is impeded and the pressure in the latter drops to the level of the surrounding space within a matter of fractions of a second. The flight crew are subjected to the action of a complex group of physical factors.

As we know, with a rapid drop (change) in pressure in the cabin, the air which is in the cavities of the internal organs, in the accessory sinuses of the nose, middle ear, and the gases in the gastrointestinal tract will unavoidably expand. The pressure in these cavities increases, leading to a sharp distention of the walls of the hollow organs. As a result, there may be severe functional and morphological changes which considerably reduce the working capacity of the pilot.

A change in barometric pressure, in accordance with the concept established in aviation physiology, is a dynamic process of a change in pressure in the medium of air surrounding the pilot and in the narrow sense is an abrupt accidental failure of the pressurization of the aircraft cabin during flight.

From the physical standpoint the change in pressure is characterized by the following principal parameters: magnitude (mm Hg), time or duration (seconds), speed (mm per second), and ratio between initial and final pressure value. This magnitude is determined by the difference in pressures in the aircraft cabin prior to decompression and after its completion. The ratio of the original pressure in the cabin to the final pressure following the change is the multiplicity factor of decompression. Its duration is governed by the time segment from the beginning of decompression until completion. The rate of /104
decompression is a derivative from the magnitude and duration of the change.

A dangerous consequence of the influence of explosive decompression is the possibility of damage and rupture of the lung tissue. The higher the absolute value of the change in pressure and the shorter the time during which it occurs, the greater the danger of traumatic damage.

A great many papers have been devoted to a study of the effect of explosive decompression on the organism. In the Soviet Union, such studies were first performed in 1939 by A. P. Apollonov, D. I. Ivanov, D. Ye. Rozenblyum and V. A. Spasskiy. The subjected animals (goats, rabbits, dogs) to the action of pressures which changed from ground level to 10,000 meters (562 mm Hg) in 2-5 seconds, with a maximum rate of change of 281 mm Hg per second. No traumatic damage to the lungs was observed under these conditions. The authors concluded that pressure changes of 220 mm Hg are safe for animal life.

V. G. Mirolyubov (1941) found that decompression at 217 mm Hg in 1-2 seconds is not dangerous to human health.

M. P. Brestkin et al. (1944) studied the influence exerted on the human organism by pressure changes of 636 mm Hg (from 760 to 124 mm Hg) in 5 seconds

and 315 mm Hg (from 405 to 90 mm Hg) in 3 seconds. They noticed no pathological changes in the organism and concluded that such pressure changes were relatively safe.

More extensive studies were performed by A. P. Apollonov, D. I. Ivanov, Z. B. Malkin, A. G. Kuznetsov, etc. The results of these studies showed that decompression of 220 mm Hg in 0.5-0.3 second (to altitudes of 30,000-35,000 m) while using oxygen supply apparatus for breathing under increased pressure poses no danger to man. They confirm that the degree of the damaging influence /105 of decompression on the organism is governed by the magnitude, rate, and multiplicity factor of the change in pressure.

F. P. Pozharisskiy, D. Ye. Rozenblyum, and I. M. Khazen (1957), in experiments on various animals (dogs, rabbits, cats, rats and mice), under decompression conditions of 140-720 mm Hg in 0.06 second (maximum rate of change equaled 12,000 mm Hg per second) confirmed that such pressure changes cause isolated morphological changes in the lungs (numerous subpleural hemorrhages, located primarily along the posterior and internal surfaces of the lower lobes of the lungs). Hitchcock (1954), studying the influence of pressure changes of 435 mm Hg at an altitude of 3,000-15,000 m in 0.2 second, found in his morphological investigations of dogs that there were extensive hemorrhages in all of the lobes of the lungs.

The majority of investigators believe that functional changes occur as the result of the reflex influence on the lungs and gastrointestinal tracts. The increase in volume that occurs at the time of decompression and affects the gases located in cavities causes a sharp distention of these organs and is the reason for significant increases in the flow of centripetal nerve impulses.

The x-ray method of investigation makes it possible to trace with sufficient clarity the dynamics of the changes in the position of the ribs and diaphragm during explosive decompression.

P. N. Ivanov (1950-1951; 1954-1955) found that, when there is a /106 pressure drop of 260 mm Hg in 1-3 seconds changes and deformation of the organs of the chest and abdominal cavities occur. Their degree depends upon the rate of pressure change.

In explosive decompression it is possible to find some structural disturbances in the organs of the chest and abdominal cavities. These changes were first described in Soviet literature in the works of A. P. Apollonov, D. I. Ivanov, D. Ye. Rozenblyum and V. A. Spasskiy (1939), M. I. Yefremova (1949, 1951), etc.

The morphological changes in the lungs during decompression have been noted to take the form of focal atelectases, emphysema of the boundary areas, small punctuate or large hemorrhages, most often beneath the visceral pleura, as well as edema of the lungs.

The proposition has been advanced that the development of atelectases of the lungs is not directly related to explosive decompression. In the opinion of

Kilches (1943), Schubert (1957), etc., atelectases develop as the result of filling of the alveoli with fluid; this occurs in the course of recompression as effective pulmonary ventilation ceases. Their development is also promoted by hemorrhages in the lungs which can lead to clogging of the bronchial passages with blood.

There are contradictory views in the literature regarding the mechanism of damage to the lungs. The majority of investigators believe that it takes placed as the result of a relatively rapid increase in pressure in the lungs and the distention of the latter at the moment of explosive decompression. Different conditions for the escape of air from different parts of the lungs lead to differences in the pressure change between these areas, thus causing the alveoli to burst.

According to our data and the data in the literature, explosive decompression exerts an influence on the condition of the accessory sinuses of the nose. Painful sensations and changes observed in the accessory sinuses must be attributed primarily to the rapid subsequent recompression. This is explained by the characteristics of the anatomical structure of these cavities, which ensure better equalization of pressure with the surrounding medium during decompression than during recompression. /107

The shock effect of expanding gases at the time the pressure change occurs in the lungs and the gastrointestinal tract produces not only local but general damaging effects on the organism. The shock wave may be recorded in the large vessels, heart, spinal cord, ventricles, and sinuses of the brain, and this apparently explains the frequent discovery of small hemorrhages of petechial type in these places.

Cases of damage to the stomach and intestine during pressure changes are very rare. Usually the effect is limited to the sphere of functional changes in various systems of the organism (respiration, circulation, central nervous system) and the sensation of pains in the stomach (M. P. Brestkin, 1944; D. I. Ivanov, 1952, etc.).

Considerable interest is aroused by work devoted to the study of the possibilities and methods of protecting the organism against the harmful effects of explosive decompression. Studies have been conducted in 2 different directions: toward an improvement of the design of pressurized cabins, excluding or retarding the changes in pressure in the event that their pressurization is disturbed, and toward direct individual protection of the organism against the action of explosive decompression by using devices that limit the immediate expansion of the lungs and gastrointestinal tract at the moment of decompression (pressurized suits, g-suits) and by using pharmacological preparations. /108

As the result of work that has been performed (A. G. Kuznetsov et al., 1950, 1957, etc.), a comparatively high degree of efficiency has been attained for pressurized suits and g-suits as means of protecting the organism against the harmful effects of explosive decompression. There is a definite advantage to using pressurized suits.

Protecting the organism against the action of explosive decompression by creating a counterpressure on the external surface of the body may be viewed not only as a means of preventing possible traumatic damage to the lungs, but as the means of decreasing the stimulation of the receptors of the pulmonary fields.

Regardless of the studies that have been conducted, the problem of the explosive decompression has still been insufficiently studied as of the present time, and the data which we have contain contradictory indications regarding the limits of tolerable levels and rates of explosive decompression both for man and animals.

It should be pointed out that in past studies slight pressure changes were produced both with respect to magnitude and speed, corresponding to the level of development of aviation in those days. On the other hand, as a rule, no dynamic clinical x-ray observations have been conducted to determine the state of the internal organs following a pressure change, and this is of considerable theoretical and practical significance.

Under rarefied atmosphere conditions, 3 states may develop which are caused by expansion of gases in the cavities of the body; conversion of nitrogen dissolved in the fluids and tissues of the organism into the gaseous state; boiling of the fluids of the organism accompanied by considerable vapor formation in the tissues and cavities of the organism. The first two states /109
have been systematically studied by many scientists for many decades and the theory of the problem has been worked out by them in considerable detail.

The third type of state has still been insufficiently studied. The possibility of its development in the organism at levels of 18,000 to 20,000 m or more in a scientifically based form was discussed as far back as the 17th and 18th centuries, but investigation under experimental conditions began only recently.

Boyle (1670) and Hoppe-Seiler (1875) were the first to describe the effect of boiling of fluids in the organism when the latter was located under conditions of extreme rarefaction of the atmosphere. Boyle observed gas levels of bubbles in the anterior chamber of the eye of the viper at high degrees of rarefaction of the atmosphere. However, his studies still did not provide any direct proof that the gas bubbles which were observed were anything more than water vapor. The contents of these bubbles may not be water vapor but gas, and in particular nitrogen.

The rapid development of aviation technology again concentrated the attention of physiologists on this problem. The phenomenon of boiling and vaporization at high altitudes, taking the form of tissue emphysema, began to be studied with particular intensity in recent years. It was established that the bubbles of water vapor occur not only in the subcutaneous cell layers but in the blood vessels, pleural cavity, and auricles. It is suggested that the bubbles that are found in the chambers of the heart are not initially but as the result of their penetration there from the pulmonary vessels. Gas bubbles in the

chambers of the heart do not consist of water vapor alone. Evidently they contain carbon dioxide, oxygen, and nitrogen. The observations that have been made are of both theorectical and great practical significance and indicate necessity of taking special preventive measures. /110

Hitchcock (1955) noted that the initial distention that occurs mainly in the abdominal cavity is caused by expansion of gas that is located in the organs and tissues and secondly by evaporation of tissue fluid. This indicates that the blood and fluids of the body literally boil at these low levels of barometric pressure.

Initially Hitchcock suggested that this secondary inflation occurs only beneath the skin. In his subsequent experiments involving sectioning of the abdominal wall and removal of skin from the extremities for the purpose of direct observation of the effect of reduced pressure on the internal organs, skeletal musculature, and connective tissue sheaths, a marked expansion was noted not only of the stomach and intestine, filled with gas, but the urinary bladder as well. This definitely was caused by liberation of dissolved gases from the urine and probably by rapid evaporation of fluid. The liver increased in size, and its outline became more rounded. Gas bubbles formed from tissue fluid were found in the skeletal musculature, and a picture of ordinary boiling developed.

In the Soviet Union, studies of decompression high altitude emphysema were first conducted by O. G. Gazenko et al. (1950), who found that, in the case of animals subjected to the influence of rarefaction corresponding to an altitude of 20,000 m, foci of inflation appeared at various points in the body beneath the skin; merging, these areas spread over the entire trunk. The animals' bodies increased considerably in volume. The foci of inflation decreased as the altitude decreased and completely disappeared at barometric pressures of 52-56 mm Hg (18,000-18,500 m). In the opinion of the authors, the basis for this phenomenon can be found in 2 physical processes: gas formation due to liberation of dissolved gases from the fluid and tissues of the organism, and the formation of vapor caused by boiling of tissue fluids in the organism.

Later A. G. Kuznetsov and P. N. Ivanov (1957, 1963) also confirmed that, in the case of animals at high altitudes subjected to the influence of rarefaction of the atmosphere to 41 mm Hg there is an increase in body volume.

Visual observations indicate that the phenomena of vapor formation occur gradually. Following a latent period (approximately 5-12 seconds), the bodies of the animals show distinctive foci of inflation or swelling beneath the skin which, peeling and raising it as it were, increase in volume, spreading out over the trunk to form a space between the skin and the subjacent layer which is filled with some kind of gas or vapor. When the ground level pressure is restored, this phenomena rapidly disappear, and the animal does not die. If the altitude is increased and the time the animal is exposed to the rarefied atmosphere is lengthened, the degree of inflation sharply rises.

In studying this phenomenon, we set ourselves the task of devising scientifically based recommendations for protecting the bones of the human hand against

vapor formation at high altitudes. Together with the x-ray studies, we investigated certain physiological (A. S. Tsivilashvili) and morphological (V. I. Nikolayeva) changes in the organism of the animals and man during changes in barometric pressure of considerable magnitudes. In the experiments we also studied the possibilities of protecting the organism under these conditions.

Characteristics of the Method of Investigation of Animals. The experiments were performed under laboratory conditions in a specially designed pressure chamber. /112

In experiments on dogs, rabbits and white rats, the influence of changes in barometric pressure in the range from 370-748 mm Hg in 0.3-0.004 second were studied. The final altitude following the balancing of pressure was within 36,000-40,000 m.

For maximum exclusion of the influence of acute hypoxia on the organism, the air in the pressure chamber was replaced by pure oxygen prior to the experiment, and the time the animals spent at the final altitude was sharply restricted. In the majority of experiments, it did not exceed 3-6 seconds and was increased to 15-20 seconds only in isolated cases. This was followed by rapid recompression, and the pressure in the chamber was raised to normal atmospheric. While the total recompression time was 30-40 seconds, the recompression time to altitudes of 5,000-6,000 m did not exceed 10-15 seconds.

Studies were conducted before the experiment (under ground conditions), at the moment of the pressure change, during recompression, and after completion of the experiment. Then x-rays of the organs of the chest were made every 24 hours in a systematic fashion until the normal picture had been completely restored or the animals died.

X-rays were made in accordance with the generally employed method. Both individual pictures with ordinary x-ray cassettes and the method of series high-speed roentgenography using special apparatus (Figure 23) were employed.

In the experiments with the rats and rabbits, a method of x-ray cinematography was used, with a French electron-optical converter (EOC) made by the firm of "Magnilux", with a screen diameter of 17.5 cm. Using a stand, the EOC was mounted on the outside surface of the pressure chamber window. /114

The windows in the walls of the pressure chamber between the x-ray tube and the animal, as well as the fluorographic screen and the motion picture apparatus, were glazed with 20-mm quartz glass.

The motion pictures were shot using a AKS-4 motion picture camera at speeds of 8-24 frames per second using RF-3 fluorographic film. The camera was equipped with a "Zonar" objective with an F-stop of 1:1.5.

An analysis of the material obtained was conducted using a KD-3 film. strip reader with normal projection and frame-by-frame display.

The results of the study of the experimental material obtained revealed that, when x-ray cinematography is used, electron-optical converters produce a tremendous increase in the capacity of the x-ray method of investigating functional and morphological changes in various internal or organs. The possibility of multiple examination and study of filmstrips makes it possible to detect a number of features which are difficult and frequently totally impossible to find in normal x-ray examination.

I. A. Shekhter and V. V. Dmokhovskiy (1957) were among the first to use x-ray cinematography employing the electron-optical converter and remarked on the advantages to be gained from using the electron-optical converters for making x-ray motion pictures of the internal organs of man. During subsequent years a number of papers appeared dealing with the use of x-ray motion pictures for diagnosis and scientific purposes, using electron-optical converters, in various diseases.

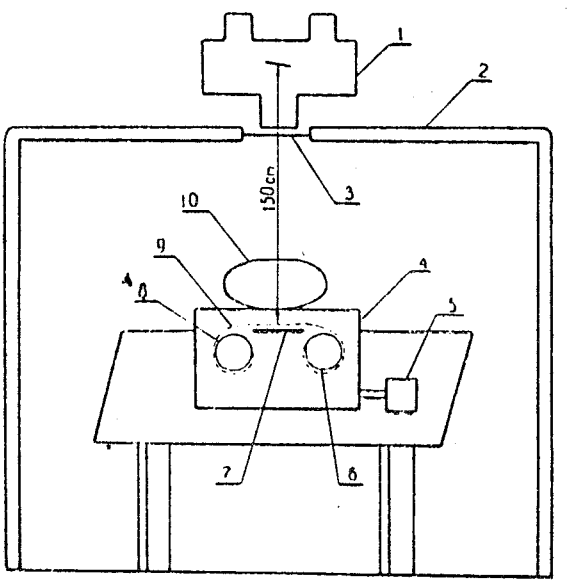

Figure 23. Schematic Diagram of the Method of Series High Speed Roentgenography in the Pressure Chamber Tests. 1, X-ray tube; 2, upper wall of pressure chamber; 3, window in the wall of the pressure chamber; 4, housing of the recording apparatus; 5, synchronous electric motor for moving the film reel; 6, reel for taking up exposed film; 7, amplifying screen; 8, reel with supply of unexposed film; 9, filmstrip; 10, object under study.

X-ray examination was conducted by us in two series of experiments. In the first, we investigated the state of the organs in the chest under the influence of changes in barometric pressure without the use of any protective measures; in the second, these measures were employed. For protection of the animals against possible traumatic injury of the organs of the chest and abdominal cavity, we used special g-suits or wrapped the trunks of the animals with bandages. /115

Under the influence of large pressure changes in microintervals of time, the organs in the chest of all the animals showed development of both functional and morphological changes. The nature and the degree of the development of these changes were functions of the experimental conditions. The distribution of the animals as a function of the experimental conditions is shown in Table 9. /113

As we can see from Table 9, pressure changes of 370-748 mm Hg were produced in the experiments.

The changes in the lungs and their distribution as a function of the type of animal are shown in Table 10. /116

TABLE 9. MAGNITUDE OF PRESSURE CHANGE (mm Hg) AND TOTAL NUMBER OF ANIMALS

Type of animal	Number	Without compensation			With compensation		
		370	590-595	730-748	370-380	590-605	748
Rats	93	78	—	—	15	—	—
Rabbits	30	—	18	—	—	12	—
Dogs	13	—	3	7	—	—	3

TABLE 10. NATURE OF THE CHANGES IN RESPIRATION FOLLOWING EXPOSURE TO THE PRESSURE CHANGE

Type of Animal	Number	Emphysema of the Lungs	Limited finely focused changes in the Lungs	Scattered, merged large shadows in the lungs	Scattered merged large shadows in the lungs with pneumohemothorax
Rats	78/15	78/5	6/10	33/0	39/0
Rabbits	18/12	18/5	6/7	6/0	12/0
Dogs	10/3	10/1	4/2	2/0	4/0

Note: The numerator shows the number of animals without use of compensatory means; the denominator shows the number of animals in which they were used.

As we can see from Table 10, those animals that were subjected to pressure changes without any compensatory means being employed were more frequently observed to have scattered, merged large shadows in the lungs with pneumohemothorax.

By using x-ray cinematography it was established that, under the influence of large and rapid pressure changes, rabbits and rats developed not only functional disturbances but also considerable morphological changes in the organs of the chest. Without using any protective means, in addition to large /117

changes in the lungs, considerable disturbances of the functional activity of the heart and diaphragm were found. They were characterized by a sharp decrease in the filling of the heart with blood. The mobility of the diaphragm in such animals was either absent or was considerably limited. A considerable increase in the volume of gas bubbles in the gastrointestinal tract was observed, together with the development of the process of vapor and gas formation in the organs and tissues.

In analyzing the x-ray motion pictures which were obtained, we noted that the degree of the observed changes in the lungs bore a certain relationship to the phase of respiration at the moment of the pressure change. The greatest changes in the x-ray picture of the lungs were obtained in those cases when the pressure change coincided with the phase of inspiration. This finding was confirmed by a sufficient number of physiological studies which indicate a lesser ability to tolerate pressure changes in the inspiration phase, when the volume of air in the lungs has reached its maximum.

The degree of distension of the lungs at the time of decompression increases so greatly that it touches off a number of functional changes by reflex means in the form of a slowing down or temporary holding of the breath, bradycardia, drop in blood pressure, etc. Excessive distention of the lungs under certain conditions can lead to serious damage to the lung tissue.

In the photographs that were taken during ejection at various altitudes and on the ground, these animals showed a decrease in the volume of the chest, displacement of the diaphragm in the cranial direction, a decrease in the size of the plumonary fields, and a considerable drop in the transparency of the lungs, against the background of the latter, there were dense large-focal shadows that merged. We know that this type of an x-ray picture is observed in the case /118 of penetrating wounds of the chest, when hemorrhages develop into the parenchyma of the lungs and the pleural cavity.

When compensatory measures are taken the changes in the x-ray picture of the organs of the chest are insignificant and are of a reversible type.

In order to illustrate the changes described above, let us examine the fluorograms shown in Figure 24.

We observed other changes as well, which are likewise of interest for an understanding of the essence of certain phenomena that occur under the effect of considerable and rapid pressure changes. These include in particular the process of vapor and gas formation in the tissues and organs. The results of our studies are in agreement with the data of other authors.

The development of the phenomena of subcutaneous emphysema in rats and rabbits took different courses. In the case of the rabbits, the visible signs of subcutaneous emphysema could be followed in photographs that were taken 0.18-0.68 second after the pressure change; in the case of the rat, however, this did not develop even after 5 to 7 seconds. This apparently has to do with the characteristics of the structure of the subcutaneous cells in these animals (Figure 25).

Figure 24. X-ray Cinematography of Organs in the Chest of Rats Number 1 and 2. a, Before the experiment; rat No. 1 without protection; rat No. 2, chest and stomach bandaged; c, 0.08 second after pressure change amounting to 370 mm Hg.

In all the animals that were not protected by bandages, the chambers of the heart were found to contain gases, which apparently came from the blood flow from the peripheral areas of the vascular system. In pictures that were taken 0.02-0.12 second or more after the pressure change, there was a considerable decrease in the size and intensity of the heart shadow, indicating a decrease in its filling with blood. Against the background of the modified heart shadow, there were areas of transparency — bubbles of vapor or gas in the blood. When the animals were permitted to remain for a longer period of time at altitude (above 19,200 m), the dimensions of the heart shadow and the area of the transparency increased.

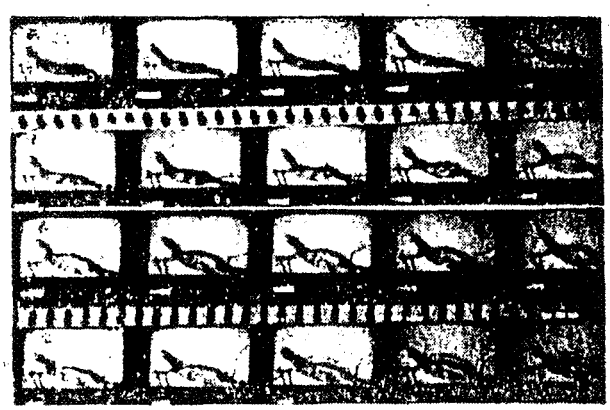

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Figure 25. X-ray Motion Picture Film of the Trunk of a Rat in Lateral Projection: a, before pressure change, b, immediately after pressure drop from 6,000 to 36,000 m. Subcutaneous emphysema not yet visible; c, 7 seconds after a pressure drop to the altitude of 36,000 m. The beginning of formation of subcutaneous emphysema can be seen; d, 11 seconds after pressure drop to altitude 36,000 m. Considerable subcutaneous emphysema is visible.

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In several experiments, even after 3.5-4 seconds spent by the rats at these altitudes, "emptying" of the heart of blood could be seen. The heart, inflated with vapor and gas, assumed a spherical shape with clearly visible walls. In the fluorograms that were taken during ejection at low altitudes (15,000 m or less), there were no areas of transparency against the background of the heart shadow. However, there was a considerable increase in the size and intensity of the heart shadow, indicating a

significant increase in its filling with blood. The dimensions and intensity of the heart shadow return to the original condition 2 hours or more after the end of the experiment.

When the trunks of the animals were bandaged, the x-ray picture of their internal organs showed no significant changes either at the time of the test or after it was over. The pictures failed to show any development of phenomena of vapor or gas formation in the organs and tissues of the animals.

Hence, the data from x-ray studies on animals revealed that large pressure changes (in thousandths of a second) produce both disturbances of the functions of the internal organs and considerable morphological changes in the lungs, which are one of the principal reasons for the death of the animals.

The data from x-ray observations were confirmed by subsequent morphological investigation of the animals. In the experiments with rats subjected to pressure changes of up to 370 mm Hg in 0.004 second to altitudes of 36,000 m, there was an increase in the volume of the lungs, their tissue was emphysematous, large areas of dark-red coloration were visible beneath the pleura, and there were small pale pink areas as well. When cut, a large amount of fluid, filled with tiny bubbles and stained with blood, flowed out. Microscopic examinations of all of the animals indicated that the lungs had been subjected to extreme overfilling of the venous vessels and capillaries with blood, with considerable hemorrhages into the parenchyma and around the vessels, and acute alveolar and interstitial emphysema. The walls of the veins were sharply scarified, stratified in some /122 vessels, and even the elastic membranes were destroyed.

When rabbits were subjected to explosive decompression at the 590-595 mm Hg level for 0.004 second, considerable damage to the internal organs was also found.

Out of 18 rabbits and 78 rats that were subjected to pressure changes without protection, 12 and 56, respectively, died after the experiment. All of the animals which had been given protective measures, regardless of the changes that occurred in the internal organs, survived.

All of the rabbits, following the pressure change without use of any protective measures, were found during the autopsy to have the pleural cavities filled with fluid blood, the apical and cardial lobes of the lungs were emphysematous, the diaphragmal lobes were uniformly stained a bluish-red color, and the tissue was slightly atelectatic. Tears in the visceral pleura and subadjacent lung tissue were located primarily in the region of the diaphragmal lobes. The heart was slightly enlarged on the right side.

Histological examination of the lungs revealed acute vesicular and interstitial emphysema, dilated venous vessels containing a lot of blood, hemorrhages surrounding the vessels and into the parenchyma, and extensive hemorrhages in the vicinity of the tears with formation of hematomas, and the lumina of the bronchi were dilated and filled with blood. The distal portions of the diaphragmal lobes of the lung tissue were in a state of complete or partial

compressive atelectasis. The myocardium was noted to have signs of minor edema of the interstitial tissue.

In experiments using external protection, pathological anatomical examination revealed no damage to the internal organs. The lungs were of /123
normal size, their tissue was slightly emphysematous in the border areas and was pale pink in color.

Beneath the microscope, the tissue of the lungs was normal in structure. The rounded areas showed slight focal vesicular emphysema, individual minor hemorrhages, small areas of atelectasis and edema surrounding certain vessels.

If the pressure change coincided with expiration, the fluorograms of the animals showed only a slight increase in the transparency of the lungs and displacement of the diaphragm in the caudal direction. In the x-rays that were taken immediately following the end of the experiment, there was a slight increase in the pulmonary picture and dilation of the shadow of the radices of the lungs, with occasional instances of limited focal shadows of flow intensity against a background of insignificant reduction of transparency of the lungs. The changes that were observed in the x-ray picture of the lungs of the animals during the first 4-6 hours, following the end of the experiment, increased. Shadows of various sizes and intensities later merged and produced a picture of an intensive homogeneous darkening of varying extent. The x-rays that were taken after 24-48 hours had elapsed following the experiment failed indicated no significant changes.

As we have already mentioned, experiments involving pressure changes of 590-595 mm Hg were performed on 3 dogs without using g-suits. An analysis of the x-rays revealed that under these conditions there were slight reversible changes primarily in the lungs. The x-ray that was taken immediately following the end of the experiment showed an increase in the intensity of the lung picture, a slight increase in the transparency of the peripheral areas of the lungs, and a slight displacement of the diaphragm in the caudal direction. In the central and lower lung fields there were isolated focal shadows of low intensity which increased in size during the next 1 to 3 days and merged. Re- /124
covery was noted on the fourth day. X-rays that were taken after 6 to 7 days indicated that there were still no changes with respect to the original picture in the lungs. During dynamic observation of these animals, a slight reversible increase was noted in the size and intensity of the heart shadow.

In experiments with dogs involving a pressure change of 730-748 mm Hg without using any method of compensation, considerable reversible and irreversible changes were observed in all cases in the organs of the chest. To illustrate these changes, we have included the following observation.

Dog "Bobit". 12 May 1960: subjected to pressure change of 748 mm Hg without use of g-suit. Figure 26 shows the x-ray of the organs in the chest of the dog prior to the experiment, while Figure 27 shows the animal after the pressure change, after the animal had been at altitude for 5 seconds. The development of altitude emphysema is clearly visible in the subcutaneous cell

structure, as well as formation of bubbles in the hollow organs; considerable expansion of the chest and displacement of the cupolae of the diaphragm in the caudal direction; considerable increase in the transparency of the lung fields. The lungs show merged cloudy shadows and scattered small circular areas of transparency. There is a considerable decrease in the size and intensity of the heart shadow. The gastrointestinal tract shows a large number of areas of transparency corresponding to the presence of gases and vapor there.

The x-ray of the organs of the chest of the same dog, taken 15 minutes following the end of the experiment (Figure 28) shows a slight expansion of the chest, considerable displacement of the cupolae of the diaphragm in the caudal direction and bilateral pneumohemothorax. The entire area of both lungs shows merged cloudy shadows (hemorrhages, edema, and atelectases) and numerous round areas of transparency of small size (bubble emphysema). There is a significant decrease in the size and intensity of the heart shadow, indicating the decrease in the filling of the chambers of the heart with blood, as in the experiments following acute hemorrhage.

Figure 26. Anterior Direct X-ray of Organs of the Chest of Dog Bobit Prior to the Experiment.

Figure 27. Anterior Direct X-ray of Organs in Chest of the Same Dog After Pressure Drop at the 5th Second of Stay at Altitude.

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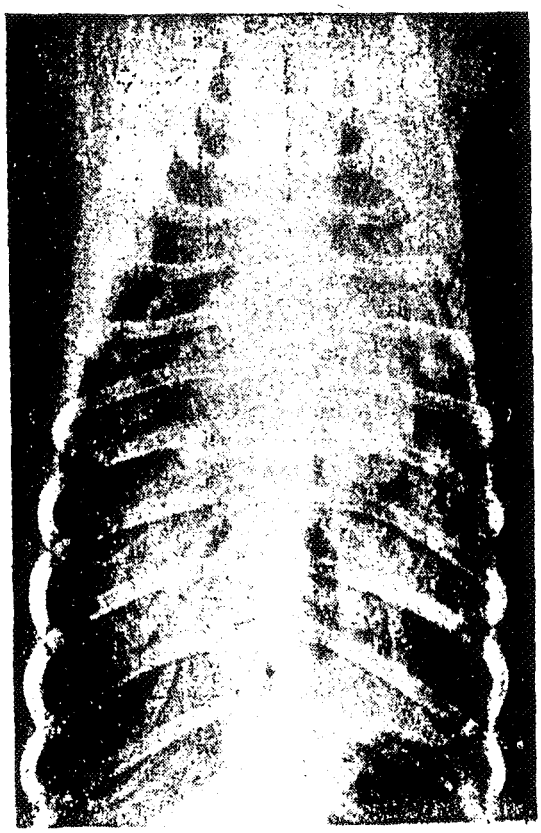

Figure 28. Anterior X-ray of Organs in Chest of Same Dog 15 Minutes After End of Experiment.

After only 30 minutes, the dog died when the above mentioned changes occurred in the organs of the chest. /128

In the autopsy which was performed immediately after the animal's death, the following was observed: the lungs were oligemic and emphysematous in the superior portions, the diaphragmal lobes were dark red in color, there were numerous ruptures of the lung tissue in the cardiac lobes on the dorsal surface and in the diaphragmal lobes along the edge, next to the costal-diaphragmal sinus, and the chambers of the heart (especially the right half) contained large dark red clots of blood and dark fluid blood.

Histological examination of the lungs revealed acute vesicular and interstitial emphysema; there were extensive areas of edema and hemorrhages; the alveolar septa were ruptured in the vicinity of the tears; extensive hemorrhages could be seen in the parenchyma and around the vessels; the walls of the latter were markedly friable, especially the fibrous layer. There were areas of incomplete atelectasis of the lung tissue. The lumina of the bronchi were dilated, especially at sites of alveolar emphysema. The myocardium displayed venous plethora and considerable dilation of the venules and capillaries. The muscle fibers of the myocardium were swollen. /127

The above changes in the width of the chest, the level of the diaphragm, and the dimensions of the heart shadow in the x-rays of the dog Bobit are shown in Table 11.

As we can see from Table 11, exposure of the dog's organism to explosive decompression at the 748 mm Hg level produced large changes in the organs ns of the chest.

Great interest attaches to the results of investigations involving a change in pressure when compensating means are used. The organs of the chest show slight reversible changes, most pronounced in the lungs: the lung picture is intensified as a result of stagnation phenomena in the vessels of the lesser circulation, their transparency is increased, and scattered, low-intensity, fine

focal shadings can be seen which disappear rapidly. They are due either to limited edemas or atelectasis of the lungs.

TABLE 11. CHANGES IN THE WIDTH OF THE CHEST, LEVEL OF THE DIAPHRAGM, AND DIMENSIONS OF HEART SHADOW OF THE DOG BOBIT BEFORE AND AFTER PRESSURE CHANGE. /129

Time of x-ray	Width of chest at the level of the 9th rib, cm	Displacement of the diaphragm with respect to the original picture, cm		Heart		
		to the right	to the left	Width, cm	Length, cm	Area cm^2
Before the experiment	12.3	0	0	7.1	9.4	48.0
After the pressure change, at the 5th second of exposure to an altitude of 40 km	14.8	Caudally by 5.2	Caudally by 5.3	5.3 -25.4	6.8 -27.7	33.0 -31.2
15 minutes after the experiment	13.6	Caudally by 0.5	Caudally by 2.3	6.7 -5.6	8.2 -12.8	40.0 -16.7

Note: - indicates a decrease in size (%).

Hence, x-ray studies confirmed the presence of functional and morphological changes in the organisms of the animals (especially in the lungs) when the latter were exposed to explosive decompression. These changes in the lungs were produced by edemas, atelectases, and hemorrhages into the lungs and the pleural cavity.

The changes in cardiac activity were probably caused by the following: indirect action on the heart by significant disruptions to the circulation of the blood in the lesser circulation, damage to the lungs, and the traumatic effect of explosive decompression on the heart.

The results of dynamic x-ray observations of the organs of the chest in animals that have been subjected to considerable and rapid pressure changes without the use of compensating devices showed that the traumatic changes which occurred in the lungs increased rapidly later on and the animals died. When compensating devices were employed, the changes in the organs of the chest were insignificant and disappeared within 3 to 5 days, followed by clinical recovery of the animals. /130

The results of the x-ray studies of the influence of explosive decompression on the animals makes it possible to draw the following conclusions.

Explosive decompression at 370 mm Hg in 0.004 second up to 36,000 m causes severe damage to the lung tissue of rats; 590 mm Hg in the same time up to 36,000--40,000 m produces serious injury to the lung tissue of rabbits and insignificant reversible changes in the lungs of dogs; at 730-748 mm Hg in the same period of time there are marked injuries to the lung tissue of dogs that lead in some cases to the death of the animals;

- The use of a g-suit during exposure to explosive decompression at 370-748 mm Hg for 0.004 second prevents the development of significant changes involving the internal organs and thereby provides the necessary protection for the animal organism against the harmful effects of decompression.

Characteristics of the Method of Investigation Involving Human Participation.

The studies were performed in a special pressure chamber, using 53 men aged 20 to 32, who had been pronounced suitable for high altitude experiments involving breathing of oxygen under high pressure by a commission of flight physicians.

The oxygen supply of the subjects was provided by various types of oxygen /131
equipment, pressure suits and space suits. The operating principle of the systems that were used for the oxygen supply at altitudes above 12,000 m was such that, beginning at this altitude, they automatically produced the necessary excess pressure in the pressurized helmet and the chambers of the tightening devices of the suit. The amount of excess pressure in the pressurized helmet and consequently in the lungs is a function of the altitude in the pressure chamber after the pressure change.

According to the accepted standards, the total pressure in the pressurized helmet, including the pressure in the pressure chamber following the pressure change at altitudes above 12,000 m, was 145 mm Hg. The studies were performed to investigate the influence on the organism produced by a pressure change in the range from 220-370 mm Hg in tenths of a second to altitudes of 30,000-36,000 m.

The general conditions of the subjects following exposure to explosive decompression was evaluated on the basis of the results of physiological and clinical x-ray investigations of the organs of the chest. On the basis of data from x-ray cinematography of the heart, possible changes in the contractile function of the myocardium as a result of exposure of the organism to high altitude tests breathing under high pressure were studied. X-ray studies of the organs of the chest were performed immediately prior to the test and 15 to 30 minutes after it was over. During the observations conducted after the test, to determine the presence of any kind of pathological changes in the lungs, additional x-ray pictures were taken at specified time intervals, until the changes that were found had completely disappeared. Series photographs in these cases, as a rule, were taken after 1 and 2 hours and after 24 hours.

In a number of cases, immediately prior to the high altitude tests and afterwards, instead of a single x-ray of the organs of the chest cavity, a series /132
of 3 pictures of the chest were taken using the modified method of Yu. N. Sokolov to detect any changes in the optical density of the lungs. One picture was taken at the end of a quiet inspiration; the second was taken at the end of maximum inspiration, and the third was taken at the end of maximum expiration. The need for this was based on available data in the literature indicating an unfavorable influence on the organism exerted by the systematic influence of increased intrapulmonary pressure.

In individuals systematically subjected to the effects of breathing under increased pressure, the condition of the organs in the chest was determined on the basis of anterior direct x-rays and x-ray kymograms that were taken before the start and after the end of these tests. If the indications were unusual, additional pictures were taken, or fluoroscopy was performed.

In a special series of experiments using individual and series x-rays, the development of high altitude tissue emphysema was studied in subjects whose wrists had compensating devices attached to them and in subjects whose wrists did not.

The studies were performed with 16 subjects aged 21 to 32, pronounced suitable for tests in the pressure chamber. The pressure chamber experiments were conducted at high altitudes both with a smooth change and with a drop in pressure to 0.3 atm in 0.3-0.6 second, with a subsequent stay of the subjects at this altitude for 5 to 16 minutes. The protective means employed were various types of compensating gloves (ordinary close-fitting, rubber or fabric). Special gloves with a layer of air to protect the dorsal surface of the wrist were also used.

X-rays were taken before the experiment, at a set altitude every 2 to 3 /133
minutes, and after the end of the experiment. One problem in the x-ray examination following exposure to changes in pressure was the detection of possible pathological changes in the organs of the chest.

Only 98 out of the 229 observations conducted after exposure of the organism to explosive decompression produced x-rays that showed various functional and morphological changes in the organs of the chest (Table 12).

Changes were frequently noted in the lungs and were characterized by an /134
increase in the transparency of the latter, an intensification of the lung picture, and developments of focal or band-like shadows in limited areas. Changes were also seen in the heart shadow. The intensification of the lung picture is of particular interest. In some cases, it had a diffuse nature, while in others it was local. By using the Val'sal'ya test, it was found that the reason for the intensification of the lung picture could be found in the changes in the hyperemia of the vessels of the lungs. During dynamic x-ray observation it was found that the lung picture as a rule returns to normal 2 to 7 days following the end of exposure to explosive decompression. As a rule, local

intensification was observed in the lower and middle fields of the lungs. This evidently has to do with the fact that, both during breathing under increased pressure and during exposure of the organism to changes in barometric pressure, the lower, more mobile parts of the lungs are subjected to greater changes.

TABLE 12. CHANGES FOLLOWING EXPOSURE OF THE HUMAN ORGANISM TO PRESSURE CHANGES

Nature of changes	Number of observations with changes	Percentage of total number of tests
Increase in the filling of the lungs with air and blood and change in heart dimensions without disruption of its contractile function	44	14.8
Discoid atelectases in the lungs	24	10.5
Discoid atelectases and increased filling of the lungs with blood	14	6.1
Increase in the filling of the lungs with air and blood	10	4.4
Increase in the filling of the lungs with blood	4	1.7
Increase in the filling of the lungs with air and blood and changes in the dimensions of the heart, with disruption of its contractile functions	2	0.9

In a number of instances, pictures taken after the end of the experiment show the presence of shadows in the lungs. As a rule, more or less similar changes were seen in the superdiaphragmal area of the lungs, consisting primarily of a horizontal arrangement of the shadow bands or the appearance of striped areas reminiscent of a picture of cirrus clouds. These changes in the upper lung areas took the form of cloud-like shadows of low intensity, without distinct contours. Later they rapidly disappeared even in those pictures taken several hours afterward or on the next day; the organs of the chest showed no important changes of any kind in comparison with the original condition. The subjects voiced no complaints. These changes disappeared without a trace in the early /135
stages. We were unable to establish a direct relationship between the recovery rate and the magnitude of the darkening which was observed. In the majority of cases, this darkening rapidly disappeared (50 to 60 minutes after the end of the

experiment), leaving no trace. In only a few scattered instances, the recovery from these changes lasted longer (up to 3-5 hours).

The data from a general clinical examination of these individuals who are required to be examined by a therapist following the end of the ascent, as a rule, failed to indicate any of the above described changes in the lungs. Only in individual cases was there clinical determination of a slight, brief slackening of respiration or fine-bubble and crepitant rales in the same area of the chest where the x-ray examination revealed slight changes.

The changes that were observed in the lungs were treated as discoid atelectases. The correctness of this explanation for these shadowy formations was demonstrated by V. Ya. Fridkin (1952) in autopsies and in histological studies.

As an example, let us look at Figures 29-31.

When atelectases appeared clinically in the lungs, as a rule, there was a considerable decrease in vital capacity. It should be pointed out that atelectases in the lungs were found only when outdated types of pressure suits were used, which allowed heterogeneity of the external compensation produced.

It is very interesting to see what causes the phenomena of atelectasis to occur. In individual subjects, the atelectases almost always develop following the end of the test without leading to any deterioration of their health. In some cases they were observed only after the first pressure change and did not appear afterward. /136

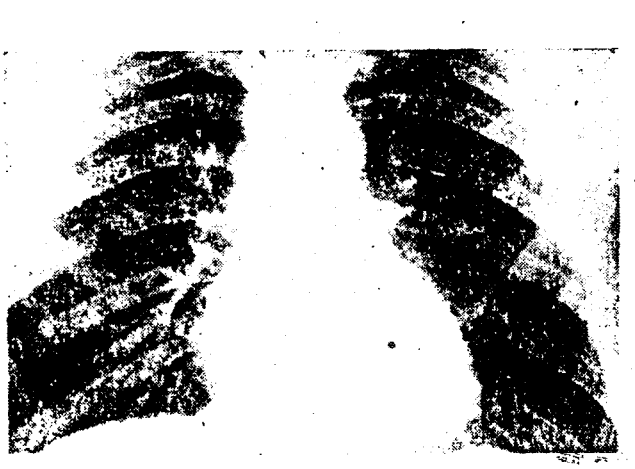

Figure 29. Anterior Direct X-ray of Organs in the Chest of Subject P at the Time of Termination of Maximum Inspiration Prior to the Test.

Figure 30. X-Ray of Organs in the Chest of the Same Subject, Ten Minutes Following the End of the Test.

Figure 31. X-ray of the Organs in the Chest of the Same Subject, 40 Minutes Following the End of the Test.

The frequent occurrence of atelectasis in individual subjects and the absence of any signs of it in the majority of others, with the experimental conditions being otherwise equal, may of itself indicate the significance of individual characteristics of the organism which promote the development of this phenomenon.

It should be pointed out that atelectases of the lungs are frequently observed even when breathing pure oxygen at normal barometric pressure.

The well known data in the /137
literature on the occupational hazards of the glassblowing industry or the playing of wind instruments, in addition to the unfavorable consequences of increased intrapulmonary pressure in certain diseases, provide a basis for believing that the study of the influence of systematic and prolonged respiration of oxygen under high pressure on the organism is of significant theoretical and practical significance. It is interesting in this regard to determine the degree to which the functional state of the lungs in man changes when breathing oxygen under pressure under the conditions of a rarefied atmosphere.

For this purpose, we conducted both ordinary x-ray investigations and /138
studies using the modified method of Yu. N. Sokolov (1947, 1951, 1956).

A visual evaluation of the x-rays showed that following the experiment 53 out of 229 cases showed a functional increase in the x-ray transparency of the lungs while 46 showed a slight reversible change in the heart shadow.

It is known that pressure changes have an unfavorable effect on the state of the accessory sinuses of the nose. We studied two groups: in the first, we included those individuals whose clinical x-ray examination revealed no changes /139
involving the accessory sinuses of the nose; the second group was made up of individuals who had been pronounced healthy by otorhinolaryngological specialists prior to the start of the experiment, but whose x-rays indicated that they had residual changes following recovery from acute inflammatory processes in the frontal and highmoric sinuses.

The subjects in the first group showed no changes of any kind in the accessory sinuses. In the second group, 2 out of the 10 subjects noticed sharp pains in the area of the highmoric and frontal sinuses when subjected to pressure changes in the pressure chamber; these pains rapidly passed when the pressure was returned to normal. After several tests, these individuals

unexpectedly developed fluid in the highmoric sinuses (Figures 32 and 33), so that further testing was suspended. The aggravation of highmoritis occurred without any noticeable subjective complaints. Subsequent tests revealed that the fluid was completely resorbed in 7 to 10 days without any medical treatment.

It should be mentioned that the aggravation of chronic inflammatory processes in the accessory sinuses of the nose was noted in dynamic observations of individuals who had not been subjected to the influence of high altitude factors. However, the aggravation in these subjects took place against a background of cold infections. These patients complained of headache, pains in the area of the inflamed sinuses, and secretions from the nose.

It is clear from the above material that the influence of changes in barometric pressure on individuals with residual symptoms following recovery from inflammatory processes in the accessory sinuses may, under certain conditions, cause aggravation of the process and the development of so-called barohighmoritis.

There is a basis for assuming that a principal role in the pathogenesis of highmoritis is played by disturbances of the circulation of the blood in the altered mucous membranes of the accessory sinuses of the nose due to the abrupt changes in barometric pressure. As was pointed out by A. P. Popov (1953), the vascular reaction evoked by a delay in equating the air pressure in pathologically modified sinuses with a rapid change in the external atmospheric pressure may lead to development of a pathological process in the sinuses which takes the form of catarrhal frontitis and highmoritis. /142

Hence, after the tests were completed, several of the subjects showed reversible changes in the lungs, heart, and accessory sinuses of the nose. Most frequently, the first symptoms were functional changes in the organs of respiration and circulation. As a rule, they proceeded without any clinical symptoms and were detected only with the aid of x-ray and other methods of investigation.

To study the remote results of investigations, the subjects were subjected to systematic and repeated exposure to pressure changes while breathing oxygen under high pressure for 1 to 2 years or more, with interruptions of 7 to 10 days between tests. During this period, the majority of the subjects showed no visible changes in the organs of the chest.

Changes in the lungs were observed in 6 out of the 53 individuals. Four of them showed perifocal infiltrative changes around the small, dense, and calcified foci in the apical-subclavicular areas of the lungs, corresponding to limited fibrous-focal tuberculosis of the lungs in the recrudescence phase.

These subjects were later excused from participation in the experiments. It is difficult to pinpoint the cause of the aggravation. During the observation period, they displayed symptoms of colds in the upper respiratory passages, which could also have changed the reactivity of the organism and could have aggravated the tubercular process. However, the influence of the pressure changes cannot be fully excluded.

Figure 32. Anterior X-ray of the Accessory Sinuses of the Nose of the Subject Prior to the Test.

Figure 33. Anterior X-ray of the Accessory Sinuses of the Nose of the Same Subject, 40 Minutes After the End of the Test. /140 /141

Facts are presented in the literature which indicate a possible relationship between the influence of changes in atmospheric pressure on the human organism and the aggravation of an obstructive process in the lungs. /143

On the basis of the above, it must be concluded that individuals with compensated forms of tuberculosis of the lungs, including those with residual symptoms of diseases of the pleura (spikes, etc.), must not be allowed to take part in high altitude experiments involving breathing under high pressure.

In two subjects who were systematically exposed to the influence of these factors, the x-rays revealed a definite hardening and deformation of the lung picture, as well as a low position of the diaphragm and a slight increase in transparency of the lower parts of the lungs, indicating the development of pneumosclerosis and emphysema.

Thus, the systematic use of respiration under high pressure has an influence on the state of elasticity of the lung parenchyma and promotes changes in the interstitial tissue.

Results of our studies are in agreement with the data in the literature which were obtained in observations of musicians who play wind instruments and of glassblowers.

Special x-ray cinematographic studies of the heart at intervals of 6 months were conducted with 8 subjects. In 3 of them the dimensions of the heart shadow were enlarged. This occurred primarily due to hypertrophy of the left ventricle. In some of the subjects, an increase in the size of the right ventricle was also noted.

Further observation obviously will make it possible to clarify to a greater degree the precise reason for the phenomena of hypertrophy of the ventricles that were observed in the subjects. It would be very interesting to determine /144
why these phenomena developed only in certain individuals, who were subjected to the same degree through the action of high altitude factors. This question still remains unclear.

On the basis of an x-ray observation, it is possible to conclude that multiple and systematic exposure to high intrapulmonary pressure for 2 years does not produce any signs of pathology in the organs of the chest in healthy individuals.

Development of High Altitude Tissue Emphysema in Unprotected Areas of the Body And Means of Protection.

A special position among decompression symptom complex factors belongs to high altitude tissue emphysema.

The data which we obtained, as well as the results of other studies (O. G. Gazenko, A. G. Kuznetsov, 1950; P. N. Ivanov, A. G. Kuznetsov, 1957, etc.) showed that, in order to prevent the development of decompression emphysema, it is necessary to exert mechanical pressure on the surface of the body which is equal to the total pressure of the external atmosphere when the latter is more than 47 mm Hg.

At the present time, flights at high altitudes involve the use of special pressure suits which exert a counterpressure on the surface of the body and make it possible to breathe oxygen at high intrapulmonary pressure, preventing the development of symptoms of boiling and vapor formation in the organism at these heights. However, these suits do not cover the entire surface of the body. The wrists remain unprotected, and this tissue emphysema develops at these points. The increase in the volume of the wrists is frequently accompanied by the development of sharp painful sensations, disruption of the fine coordinated movements of the wrists and fingers, and a considerable decrease in the muscular strength of the wrists. This may have a negative effect on the pilot, increasing his emotional stress. It has become necessary to develop special means of pro- /145
tecting the hands against decompression tissue emphysema at high altitudes.

To solve this problem, x-rays were taken of the wrists. Studies the resultant x-rays revealed that, as a result of a stay of a human subject in a

rarefied atmosphere, where the pressure was less than 45 mm Hg, the unprotected areas of the body developed areas of transparency — subcutaneous emphysema. The development of such areas, as a rule, could be seen 3 to 10 minutes into the exposure of the subjects to the high altitude conditions. As the length of their exposure to the high altitude conditions increased, an increase in the severity of these changes could be detected. As the degree of subcutaneous emphysema rose, separation of the layers of the cutaneous covering became more and more severe. The time spent at altitude and the degree of subcutaneous emphysema were governed by the anatomical characteristics of the structure of the tissues of thw wrists. In areas which are richly supplied with friable subcutaneous cell structure, these changes occurred earlier and developed very rapidly. The development of subcutaneous emphysema occurred first of all on the dorsal surface of the wrist. Development of similar changes of the area of the radiocarpal joint and the plam occurred later and to a much lesser degree in comparison with the dorsal surface. For the sake of an illustration of the changes described above, let us look at Figure 34.

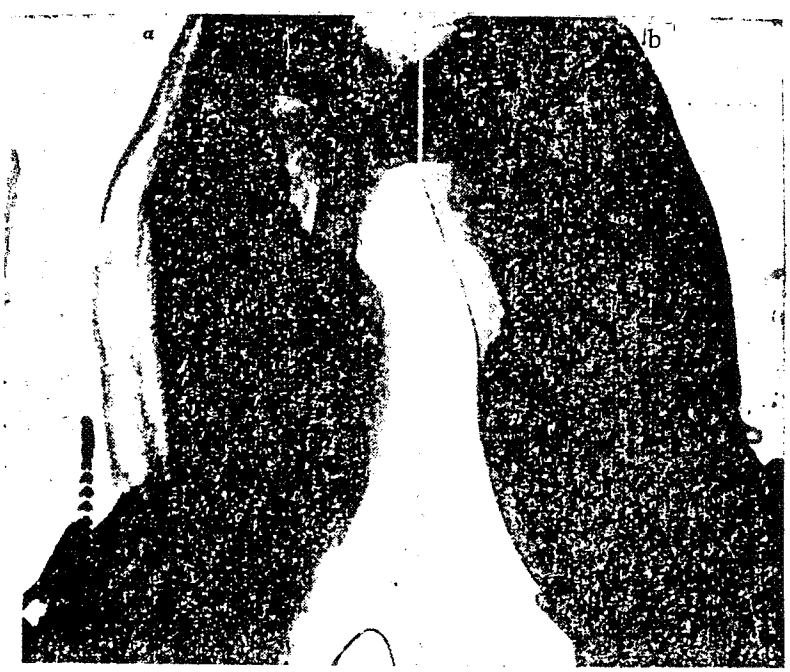

Figure 34. Profile X-ray of Both Wrists of Subject S at the Tenth Minute of Exposure to an Altitude of 30,000 m. a, Right wrist without compensation; b, left wrist with compensation (under pressure of 50 mm Hg). /146

In x-rays taken 5 minutes after ascent to an altitude of 4,000 m, there are still no transparent areas in the soft tissues of the wrist and the radiocarpal joint.

Interesting data have been obtained in studies with compensation of the wrist. Dependence of the formation of the subcutaneous emphysema upon the degree

pressure developed on the surface was observed. When the pressure developed on the surface of the wrist was equal to 50 mm Hg per cm^2, there was no formation of subcutaneous emphysema when the subject was exposed to high altitude conditions. /147

At low pressure levels on the wrist, the formation of subcutaneous emphysema was not prevented.

It is characteristic that, at altitudes above 25,000 m, the subcutaneous emphysema which develops is usually accompanied by sharp pain, while at lower altitudes no pain is felt. Following the experiments, no changes could be detected in the subject's condition which were related to subcutaneous emphysema.

The results of the studies revealed that compensating gloves are an efficient means of protection against the development of tissue decompression emphysema in the wrists in those cases when they are properly fitted and the rules for their use are followed. When larger gloves are deliberately worn, the development of tissue emphysema is not prevented.

Thus, when the organism is subjected to considerably changes in barometric pressure, both functional and morphological changes occur in the organs of the chest. These changes are particularly marked in the lungs.

The development of atelectases in the lungs following high altitude experiments is of practical and theoretical importance.

The data which we obtained and the results of other investigations (P. N. Ivanov, 1959; D. I. Ivanov, A. S. Tsivalishvili, 1967, etc.) showed that the atelectases of the lungs which were found were not the direct consequence of explosive decompression. They were also observed in experiments where there was no rapid decompression.

A great many papers have been devoted to the development of atelectases in the lungs; these works describe the etiology and pathogenesis of this process on the basis of experiments and clinical observations. At the present time, it is generally accepted that the basis for the development of this phenomenon is the resorption of oxygen during mechanical disturbance of bronchial permeability, reflex-vasomotor reaction, and external compression.

Regardless of the limited amount of data obtained as a result of an analysis of the available material, several points should be made regarding the mechanism of development of the symptoms of atelectasis which develop in subjects. Inasmuch as these phenomena are observed only after experiments have been performed involving the use of outdated types of compensating clothing, we can assume that the external compensation which these suits produce is not uniform. It is clear that insufficient respiratory functioning of the diaphragm under these conditions is important.

The presence of constant high pressure in the lungs as a necessary means of supplying oxygen to the organism while it is exposed to high altitude conditions excludes the possibility of the development of atelectases under these conditions. Therefore the symptoms of atelectasis which do appear have to do with recompression, when the intrapulmonary pressure is equated with the surrounding atmosphere. Under these conditions, prerequisites may be created for nonuniform ventilation of various parts of the lungs. The fact that the development of atelectases has to do with the moment of recompression is demonstrated by pathomorphological studies of animals using a special method (V. N. Vinogradov, 1963, 1967).

The development of atelectases probably has a direct relationship to the individual morphological and functional characteristics of the respiratory system of the subject. The frequency of development of atelectases in some persons and scattered instances of this development in another small group of subjects with the test conditions being the same indicates that they are of different origin. It is clear that multiple development of atelectasis /149
following high altitude experiments can very likely be linked in turn to some mechanical process: occlusion of the bronchus by mucus or its compression by adjacent emphysematous dilated areas of lung tissue. The rare isolated cases which usually occur during the first high altitude experiment involving the development of atelectasis clearly must be attributed to reflex-vasomotor reactions for their origin to a large extent.

The results of x-ray studies allow us to draw the following conclusions:

- the diaphragmal lobes of the lungs are frequently damaged in explosive decompression when protective means are not employed. The most characteristic morphological changes in the lungs are hemorrhages, atelectases, emphysema, and pneumohemothorax. A definite relationship between the observed changes in the lungs and the phase of respiration has also been established: the greater the degree to which the lungs are filled with air at the time the pressure change occurs, the more significant the changes will be;

- explosive decompression at 730-748 mm Hg in 0.004 second causes serious damage to the internal organs of dogs, in some cases leading to the death of the animal;

- the use of a pressure suit during exposure to explosive decompression at 370-748 mm Hg in 0.004 second prevents the development of significant changes involving the internal organs, and thereby ensures the necessary protection of the organism of the animal against the harmful effects of this factor;

- following the end of the experiment involving exposure of the organism to pressure changes while breathing oxygen under high pressure, some of the subjects had an increase in the hyperemia of the vessels of the lungs, development /150
of atelectases of the lungs, and an increase in heart size. These changes were of a reversible nature;

- systematic and multiple (more than 2 years) exposure of the human organism to pressure changes and excess intrapulmonary pressure leads to a decrease in the elasticity of the lung tissue, the development of emphysema, and symptoms of pneumosclerosis;

- at altitudes above 19,200 m, unprotected areas of the body (wrists) develop high altitude tissue emphysema. Compensating gloves completely prevent the development of tissue decompression emphysema.

Conclusions

Flight aboard supersonic aircraft and spacecraft, especially in emergency /151
situations, involves the exposure of the crew to a number of unfavorable factors: sudden and prolonged g-forces, angular accelerations, explosive decompression, breathing of oxygen under high pressure, etc.

Successful high altitude and spaceflight by man was preceded by numerous medical and biological studies performed both in the Soviet Union and abroad. In their works, the majority of scientists made extensive use of physiological methods of investigation, but rarely used x-rays. However, intravital diagnosis of several disturbances in the organism is impossible without the use of x-ray studies. This method makes it possible to detect and observe under dynamic conditions the functional and morphological changes which may occur in various organs and systems.

During exposure of the organism to various flight factors under experimental conditions, we performed the following x-ray studies: the taking of x-ray photographs, roentgenoscopy, roentgenokymography, angiocardiography, and x-ray cinematography. The effect of sudden and prolonged exposures to g-forces on the organism was also studied, in addition to the effects of /152
angular accelerations and large and rapid changes in barometric pressure. In addition, the effectiveness of pressure and g-suits was determined. Principal attention was devoted to determining the nature of the changes in the cardiovascular and respiratory systems and the skeletal apparatus under the influence of these factors.

The exposure of the organism to sudden g-forces leads to displacement and deformation of various organs and tissues. At high levels both reversible and irreversible changes in the bone structure and internal organs are noted. The damaging effect is a function of the parameters of the sudden g-force, the conditions of its action on the organism, and certain anatomical-morphological characteristics of the organs and tissues of the body.

In experiments on animals involving exposure to sudden g-forces with a magnitude of 50-1,000 units in times of 0.02-0.002 second, fractures of the vertebrae and ribs were seen, together with stagnation phenomena in the lesser blood circulation, hemorrhages, edema and atelectases in the lung tissue, emphysema of the lungs, pneumothorax, and a significant disruption of the functional activity of the heart.

When sudden g-forces in various directions are applied, changes of different kinds occur. While the action of g-forces in the head-pelvis direction initially produces bone damage and morphological changes in the organs of the chest later on, g-forces acting in the back-chest direction initially produce changes in the organs of the chest and later damage bones.

We established the possibility of protecting the organism against harmful effects of seven g-force applications. Thus, for example, by using a plaster cast or submerging an animal in water using a pressurized jacket, no damage to /153
bones was noted; likewise, there were no significant changes in the organs of the chest even with exposure to sudden g-forces with a magnitude of 600-1,000 units. The insignificant changes that occur under these conditions, primarily in the lungs, were found to be of a reversible nature. The fundamental reason for the good protection of the organism under these conditions is the uniform distribution of the g-force over the entire body.

When the organism is exposed to prolonged g-forces, there is a displacement and deformation of the internal organs, disturbance of the filling of the heart with blood, and a change in the blood flow in the lesser circulatory system.

The degree and nature of the changes which occur is a function of the following factors: direction of the g-forces, magnitude and duration of its actions, rate of rise, and the physiological state of the organism.

The problems with the circulatory system that arise under the influence of g-forces are critical to the development of profound disturbances in the functional activity of the organism.

Simultaneously with the x-ray studies of the heart and aorta of the subjects, we investigated the condition of the lung picture in order to clarify the changes which occur in the lesser circulation. When the organism is subjected to g-forces in the head-pelvis direction, there is a loss of blood from the upper areas of the lungs so that the lower areas show a marked increase in the lung picture. The development of a symptom of this kind may be explained by the development of stagnation phenomena in the vessels of the area of the lung in question.

Recently considerable attention has been devoted to the study of the influence exerted on the human body by transversely directed g-forces. The /154
x-ray studies that have been conducted have shown that, in the case of transversely directed g-forces with a magnitude of up to 5 units, acting at an angle of 78 degrees to the acceleration vector, the general hemodynamics changes to a lesser degree. However, the capacities of the organism are not unlimited. If an individual is subjected to the action of more significant levels of transverse g-forces for a long period of time, considerable disruptions may be observed in the activity of the cardiovascular system, especially the vessels of the lesser circulation. Frequently there are stagnation phenomena in the vessels of the lesser circulation followed by development of edema and atelectases in the lungs, which are frequently detected by using x-ray or pathomorphological methods of investigation. Other authors have also mentioned the

frequent development of fine-focal atelactatic areas in the lung tissue as the result of the action of prolonged g-forces of high magnitudes.

Flight aboard spacecraft in orbit and returning to the Earth, when the stabilization system of the craft is operating with insufficient accuracy, as well as prolonged free fall of the body when parachuting, as a rule, is accompanied by rotation of the individual around an axis passing through any one of many directions relative to the body.

At the present time, the influence of the forces acting on the pilot as he turns in his chair in the air have been insufficiently studied. Until recently, the influence of angular accelerations had been studied for a relatively short period — several seconds, with respect to only one plane, which was frequently encountered during rotation around the center of gravity during ejection. Under the conditions of the development of rocket technology and the conquest of space, new requirements are being raised in conjunction with this problem. /155

The data from x-ray studies of subjects have shown that certain functional changes in the organs of the chest occur under the influence of multiple angular accelerations: phenomena of stagnation in the vessels of the lungs and an increase in the filling of the heart with blood, the latter being accompanied in some cases by a disruption of the contractile function of the myocardium.

In certain individuals who have little resistance to the effects of angular accelerations, following the end of rotation there is a considerable change in the contractile function of the heart, taking the form of a lack of pulsation in limited areas of the organ. Disruption of the contractile function of the myocardium following the experiments in a rotating chair, in our opinion, is related to the reflex vasomotor disturbance of the coronary blood circulation, leading to a temporary disruption of the blood supply to the heart muscle. Obviously this reflex reaction is caused by an extreme stimulation of the vestibular apparatus under the influence of multiple exposures to angular accelerations.

The data obtained during the exposure of the organism to angular accelerations of considerable magnitudes indicate the necessity for a strict medical surveillance of the state of health of the subjects.

The most dangerous consequences of explosive decompression are damage and rupture of lung tissue. As the absolute value of the pressure change increases and the time of its duration decreases, the danger of the traumatic effect rises.

We have studied the influence of explosive decompression primarily on the state of the organs of the chest and the accessory sinuses of the nose. In the course of the x-ray studies, we also examined certain problems having to do with the phenomenon of boiling of the fluids of the organism under conditions of a rarefied atmosphere, as is observed at altitudes above 19,000 m.

The large pressure changes, in addition to disturbances of the functions of the internal organs, also caused marked morphological changes in the lungs which constituted one of the principal reasons for the death of animals.

The reaction of the organism to the explosive decompression is a function of a number of factors: the absolute value of the change in barometric pressure, the rate and frequency of decompression, the phases of the respiratory cycle during which the pressure change occurs, the amount of gas in the intestine immediately before decompression, and finally, species and individual characteristics of the organism.

Damage to the lungs is the result of a sudden increase in the intrapulmonary pressure which occurs during explosive decompression. The cause of these injuries can be found in two mechanisms: first of all, sudden rapid dilation of the lungs due to a sudden drop in the surrounding atmospheric pressure, leading to stretching of the alveolar septa and a stressing of the lung tissue around the bronchi and large vessels, and secondly, the impact of the lung tissue against the denser surface of the rib cage, heart, large vessels, or liver. In both cases, hemorrhages may occur as the result of tearing or contusion of the lung tissue. It should be pointed out that the basic damaging mechanism involved when the organism is subjected to explosive decompression is excessive distention of the lungs.

The results of dynamic x-ray observations of the organs in the chests of animals subjected to considerable and rapid pressure changes without the use of any protective measures have shown that the traumatic changes that occur in the lungs in certain animals became more serious later on and the animals died. /157

In cases where the organism was protected during explosive decompression, the changes in the organs of the chest were insignificant and disappeared during the following 3 to 5 days, when clinical recovery of the animals took place.

All of the tests involving the influence exerted on the human organism by changes in barometric pressure were conducted using pressure suits and oxygen respiration under high pressure. When using special high altitude equipment, extreme dilation of the chest and abdominal cavity is prevented at the moment of decompression, and thereby the danger of the development of serious functional and structural changes is avoided.

After exposure to a change in pressure, the majority of subjects showed no changes in the organs of the chest. However, in a number of observations, the x-rays showed different functional and morphological variations: increased hyperemia of the vessels in the lungs, acute emphysema, discoid atelectases in the basal areas, and an increase in heart size.

The changes that were observed immediately following the end of the high altitude tests had a functional reversible nature and disappeared in the course of the first seven days. X-ray observations that were conducted following the end of multiple exposures to high intrapulmonary pressure (intervals of 7 to 10

days between tests) showed that. during systematic (over 1 to 2 years) use of respiration under pressure, the subjects failed to develop any irreversible pathological changes in the organs of the chest. However, when the test period was increased to 3 years or more pathological changes could develop in the lungs. They were revealed in the x-rays as an increase in the transparency of /158
the lung fields and a steady intensification and deformation of the lung picture, indicating the development of emphysema of the lungs and pneumosclerosis.

Taking into account the data presented above, it is obvious that we must limit to two years the systematic participation of subjects in experiments involving prolonged (more than 10 to 15 minutes) respiration under high pressure.

The influence of changes in barometric pressure on individuals with residual symptoms following recovery from inflammatory processes in the accessory sinuses of the nose may lead to aggravation of the process and the development of barohighmoritis in these individuals. Expert evaluation of the x-ray observations must be conducted in conjunction with otorhinolaryngological examination and the results of studying the nature of the tolerance of "ascents" in the pressure chamber.

A special place among decompression phenomena is occupied by high altitude tissue emphysema which occurs on the exposed areas of the human body and is accompanied by a sensation of unpleasant stress on the tissues and only in rare cases by minor painful sensations. If it reaches significant proportions, it may limit the mobility of the part of the body that is involved, for example, the wrist.

To prevent the development of decompression emphysema, it is necessary to use an amount of mechanical pressure against the surface of the body which, together with the external atmospheric pressure, will be more than 47 mm Hg.

By using pressurized clothing, which creates a counterpressure against the surface of the body, it is possible to provide oxygen respiration under high intrapulmonary pressure and thereby prevent the development of phenomena of boiling and vapor formation in the organism at high altitudes. However, these /159
suits do not cover the entire body surface; the wrists remain unprotected. Therefore it is necessary to develop special means of protecting the hands against decompression tissue emphysema at high altitudes. As a result of x--ray studies, the efficiency of compensating gloves has been demonstrated; these gloves prevent the development of high altitude emphysema in the hands and thereby maintain their normal mobility and working capacity.

Thus, during exposure of the organism to g-forces, angular accelerations, and explosive decompression, changes are noted in various organs. The x-ray data that has been collected indicate the possibility of the development of symptom--free changes involving the internal organs and bones. This indicates a need for performing clinical x-ray checks of individuals who are to be subjected to the action of such factors for purposes of timely diagnosis, prevention, and prescription of treatment.

We suggest that the use of complex clinical, physiological, and x-ray methods of investigation of the effect of extremal factors will make is possible not only to discover the mechanisms by which these problems occur but also to work out more effective means of protecting the organism.

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